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# Patterns of surfactant toxicity to plant tissues

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# PATTERNS OF SURFACTANT TOXICITY TO PLANT TISSUES

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# INTRODUCTION

Surfactants have been used extensively during the past few years in the formulation of pesticides. The inclusion of surfactants in herbicide formulations is used routinely to modify herbicidal selectivity or to intensify the effects on undersirable species of plants. Surfactants are used to increase penetration of water through turf and may alter water penetration in soils.

Surfactants are materials that by their presence at very low concentrations substantially lower the surface tension of water. An effective surfactant is composed of molecules containing an alkane-type group which is oil soluble and one or more polar groups, which are water soluble. Many plant systems are affected to some extent by treatments of surfactants. Enzyme, mitochondrial, and membrane systems along with many plant responses such as germination and growth are affected. Many of these effects have been the object of numerous investigations; however, either a narrow selection of surfactants or a limited number of test systems have prevented accurate generalizations regarding toxicity.

The present investigation has attempted to assess the toxic effect of selected surfactants of differing chemical identities using various biological criteria or bioassay systems. Among these were effects on seed germination, effects on elongation of corn radicles, responses of plants to foliar applications, soil applications, and the inclusion of surfactants in water culture. The responses of cells from beet root tissue, as evidenced by differential loss of cell pigments, were preliminary criteria of the possible general effect of surfactants on cell

membrane permeability. The concept of a general effect of surfactants on cell membranes was explored further in a limited investigation of the effects of surfactants on the ultramicrostructure of the cells of leaf tissue exposed to a selected few surfactants. Observations using electron microscopic techniques suggested that disruption of cellular organization might be the common denominator of the similar response patterns observed with the other assay systems.

# REVIEW OF LITERATURE

Surfactants are used extensively in the formulation and application of pesticides. Enhancement of pesticide effectiveness is attributed generally to physical effects on the water carrier and the dispersed phase. Observed plant reactions, coupled with the related health aspects of surfactant use, have promoted detailed investigations of cell reactions to surfactants.

This widespread use of surfactants to modify the physical characteristics of water has focused attention on the importance of surfactant effects on plants, animals, and man. Numerous investigations have shown that many surfactants may affect plant and animal cells and tissues. In plants, the processes of seed germination, root elongation, and cell membrane permeability appear most sensitive. Surfactants may produce extensive changes on enzymes, mitochondria, and membranes -- systems common to both plants and animals. These influences are often related to the structure of the surfactant, and may be modified by changes in molecular arrangement or composition.

## Surfactants and Pesticidal Effectiveness

The addition of surfactants to herbicide sprays is an established method of increasing toxicity. Blackman et al. (1958) stated that, in general, lowering of the surface tension reduces the volume of spray retained by species that are readily wetted, and conversely, increases that by species not readily wetted. These conclusions were based on experiments with peas and Brassica alba. The results agreed with those of Moore (1921), who concluded much earlier that some surfactants increased

spreading on waxy or non-waxy surfaces, but not necessarily both. McWhorter (1963a) found that a polyoxyethylene thioether increased the activity of Dalapon on Johnsongrass. Using Diuron for the control of crabgrass, Digitaria sanguinalis, McWhorter (1963b) also found that any one of several ethoxylated nonionic surfactants in aqueous spray mixtures greatly increased the herbicidal activity. Phytotoxicity of Diuron was greatest when the surfactant contained 65 percent, or approximately 9 to 10 moles, of ethylene oxide; however, materials containing 75 to 86 percent, or approximately 15 to 30 moles, of ethylene oxide were also effective in increasing Diuron toxicity. Wettability, as indicated by the Draves test, of the latter solution was considerably poorer than in the former. Surfactants containing tridecanol and alkylthiol hydrophobes were essentially as effective in increasing Diuron toxicity as were the nonyl phenol compounds. Dodecylphenol surfactants were only slightly less effective.

Leonard (1958) reported that Vatsol OT was most effective and Tween 20 + furfurylamine the least effective in increasing herbicidal effectiveness with the triethylamine formulation of 2,4-D when applied as a drop to a leaf surface. Tween 20 was the most effective material tested when 2,4-D was applied as a spray; maximum effectiveness occurred at about 500 ppm. of surfactant. Each of two polyoxyethylene sorbitan hexalaurates of widely differing molecular weights gave responses similar to those observed with Tween 20.

Staniforth and Loomis (1949) found that wetting agents reduce the selectivity of 2,4-D and enhance the rate and severity of the plant reaction. Ennis (1951) also found that surfactants enhanced the herbicidal

properties of 2,4-D, and 2,4,5-T. A number of other investigators have reported increased activity when various surfactants were added to herbicide formulations and spray mixtures (Hamner and Chi-Kien, 1948; Hamner et al., 1947; Hitchcock and Zimmerman, 1948; Lucas and Hamner, 1947; Marth et al., 1945; Gertsch, 1953; Leonard and Crafts, 1956; Blackman, 1950; Blair and Fuller, 1952; Crafts, 1956; Ennis, 1951; Freed and Montgomery, 1958; Hamilton and Palmiter, 1951; Hauser, 1952; Laning and Aldrich, 1951; Mitchell and Linder, 1950, 1957; Skogley, 1954; Staniforth and Bryan, 1950; Thimann, 1948; and Holly, 1956).

Currier and Dybing (1959) and Holly (1964) suggest a number of possible ways that surface-active agents may influence the effectiveness of herbicides. Included are increases or decreases in spray retention depending upon leaf surface characteristics and a multiplicity of effects on penetration into the plant tissue. These might include retention at sites favorable to penetration, increasing area available for penetration, increasing area of contact, increasing period of penetration by acting as a humectant, by affecting cell permeability, and by acting as a cosolvent or solubilizing agent. Surfactants may increase direct penetration through stomates by lowering the surface tension of the spray solution or facilitate movement along cell walls by lowering the interfacial tension.

Using labeled 2,4-D, Crafts (1956) showed that wetting agents enhanced the absorption of the herbicide. The distribution of 2,4-D in the plant was not altered and comparable results were obtained with both 1.0 or 0.1 percent concentrations of surfactant. Freed and Montgomery (1958) showed that surfactants increased absorption of Amitrol by foliage. Although reduction of surface tension was important, they showed that the

relationship of molecular interaction between surfactant and the herbicide was of equal or more importance than lowering of the surface tension. They further suggested a highly specific requirement for surfactant formulation to fit the herbicide in order to achieve maximum effectiveness.

Sargent and Blackman (1962) found that the surfactant Tween 20 increased the rate of penetration of 2,4-D in the dark into the abaxial and the adaxial surfaces of Phaseolus vulgaris. The amount of 2,4-D entering the leaf increased with an increase in surfactant concentration up to 0.05 percent; beyond 0.05 percent, no further effect was observed. Teubner et al. (1957) found that Tween 20 was ineffective in enhancing the penetration of labeled phosphorus ($P^{32}$) into bean leaves. Other workers (Barrier and Loomis, 1957; Koontz and Biddulph, 1957; Swanson and Whitney, 1953) have shown that surfactants may actually decrease absorption of phosphates. Potassium uptake by excised barley roots was shown by Parr and Norman (1964) to be repressed by low concentrations of Tween 20 and Tween 80. Tween 20 was effective in promoting penetration of foliar-applied gibberellic acid in maize (Neely and Phinney, 1957). Triton X-100 depressed absorption of magnesium by promoted absorption of phosphorus into apple leaves (Fisher and Walker, 1955).

Other workers also have demonstrated an increase in herbicide penetration by the inclusion of surface-active agents. Hauser (1955) found a marked increase in penetration of 2,4-D into corn and soybeans when a surfactant was present. Dybing and Currier (1959), using a fluorescent dye in studying penetration, found that surfactants greatly enhanced foliar penetration in Zebrina pendula. In all cases where the surfactant was present, penetration of the lower surface was more rapid than the

upper surface. These investigators concluded that solutions containing a surfactant penetrated mainly by way of open stomata.

Surfactants also have been reported to increase the action of defoliants. Brown (1957) and Swales and Williams (1956) reported an increase in effectiveness of concentrated fungicidal sprays for the control of apple scab by the addition of nonionic surface-active agents. Their data indicate that the surfactant had little effect on the amount of insecticide deposited. Increase in effectiveness was credited to greater uniformity of the deposit.

## Effects of Surface-Active Materials on Germination of Seed

Curici-Galletti (1924) treated seed of Canabis sativa, Helianthus annuus, and Ricinus communis for two hours in a 0.1 percent saponin solution, after which seed were removed, dried on blotting paper, and allowed to germinate in sterilized germinators. Comparison with non-treated seed indicated that saponin hastened germination. Additional experiments showed that development of the seedlings was not affected by the treatment. Balansard and Pellissier (1943a) showed that a soapbark saponin accelerated germination of wheat; the minimum effective concentration was 1:300,000 with the optimum concentration for acceleration being 1:50,000. Higher concentrations (1:100 to 1:500) first stimulated and then exerted a toxic action on germination. Later, Balansard and Pellissier (1944a) showed that wheat germination was accelerated when soaked for 24 hours in a 1:10,000 to 1:100,000 concentration of dodecyl sodium sulfate. The growth of young seedlings was retarded by a 1:100,000 solution, but was

not affected by a 1:10,000 solution. Concentrations of 1:100 to 1:5,000 were toxic.

Soaking tomato seed 24 hours in a dilute saponin solution accelerated germination and growth of the seedlings (Balansard and Pellissier, 1945). It was suggested that there was a possible stimulation of growth hormone formation. A Quillaya saponin at 1:20,000 concentration accelerated germination of corn (Balansard et al., 1946), and stimulated growth for the first few days. Both Quillaya and Sapindus saponins at 1:50,000 concentration accelerated water absorption by moistened seed.

## Effect of Surfactants on Roots

The response of wheat roots to surfactants in solution was studied by Prill et al. (1949). Thirteen different surfactants were used, representing the nonionics, the anionics, the cationics, and two soybean phosphatides. The commercial agents of the nonionic type and the soybean phosphatides showed little effect except at very high concentrations, at which they were slightly inhibitory to root elongation. Saponin, a natural agent of the nonionic type, was very inhibitory. The cationics and the anionics were found to be definitely inhibitory at concentrations as low as 20 ppm. At least two surfactants were found to be slightly stimulatory at very low concentrations.

Parr and Norman (1964) treated cucumber seed with nonionic surfactants and measured the subsequent elongation of the primary root of the seedlings which were cultured in the dark for 96 hours. At 0.01 percent volume per volume, all of the surfactants tested brought about some repression of root elongation; half of them reduced the length by more than 30 percent.

Increasing the concentration above 0.01 percent resulted in still further repression of elongation. Root hair development was hampered at 0.01 percent, and at all concentrations of 0.05 percent, root hairs were absent. Number and length of lateral roots were also reduced with higher concentrations. Northen (1964) further demonstrated that detergents in concentrations of 10,000 ppm. prevented germination of radish, and consequently repressed root elongation. Concentrations of 100 and 1,000 ppm. had little effect on peas, radish, and dill. The effects on weight of seedling barley roots were also determined.

Barley roots were found to be less sensitive than were those of cucumber; but again, half of the compounds tested reduced the root length by at least 10 percent. In some cases, there was considerable stimulation of growth of other organs (root, leaf, or coleoptile). In general, the polyethylene sorbitan fatty acid esters were less inhibitory to roots than those with either ether or ether-alcohol structures.

Euler (1946) showed that root development of Lepidium sativum and Hordeum vulgare was inhibited 60 to 90 percent by treatment with 0.02 percent digitonin or 0.03 percent Quillaya saponin. Coleoptiles were the same length as the controls.

Balansard and Pellissier (1944b) showed that some cereal plants grew faster and in the latter stages of growth were larger and had more stalks and roots per plant than the controls when the seeds were treated with dilute concentrations of Polygola and Sapindus saponins. They also found that application of dilute saponin solution to the roots of tomatoes had a toxic effect, sometimes preceded by a short period of stimulation (1945). Isolated wheat embryos immersed in 1:500,000 to 1:1,000,000 aqueous solution

of saponin from Quillaya saponaria produced a greater amount of growth than did the control embryos (Balansard and Pellissier, 1943b). It was suggested that the saponin affects the embryos like a growth hormone.

The alkaloid yield of Dactura tatula was increased by 40 percent following a soil application of Tween 20 (Beal, 1954). Foliar application of the same material did not change alkaloid content. Stowe (1958) showed that some members of the Tweens stimulated growth of pea epicotyl sections. The increased growth was shown to be due to a stimulation of auxin and gibberellin action by the fatty acid esters. It was suggested further that their role in normal plant growth regulation may be exerted through a synergistic affect on hormones rather than as hormones themselves. Stowe (1960) reported later that several nonionic surfactants such as Igepal Co-610, Co-630, and Co-710 (nonyl phenoxy polyoxyethylenes), the Pluronics and Tetronics (polyoxy propylene-polyoxyethylene condensates) were inactive in stimulating growth over a wide range of concentrations. Alrowet D65, an anionic, and Sarkosyl NL-30, "O", and "S", cationic detergents, were either impotent or inhibitory. Jansen et al. (1961) sprayed soybeans and corn with various combinations of herbicide-surfactant systems, which included treatments with surfactants alone. Although many of the surfactants showed inherent phytotoxicity, especially at higher concentrations, a number were found to stimulate growth at lower concentrations. Both stimulatory and inhibitory effects were demonstrated in all ionogenic classes. Surfactant effects were not always the same on both corn and soybeans.

Growth of certain lactic acid bacteria is stimulated by some members of the Tween detergents (Williams, 1947). Heavy growth was supported by the oleic acid containing Tweens 80 and 85; Tweens 40 and 60, which contain

palmitic and stearic acid respectively, were inactive. The growth promoting property was attributed to the oleic acid content of certain members of the Tweens. Tween 20, which contains lauric acid, also was found to stimulate growth; however, this stimulation was attributed to contamination with utilizable fatty acids. Tani and Tatsumi (1958) further showed that Tween 80 stimulated growth of hiochi bacteria in a synthetic medium. Generally, surfactants having oleic acid as the hydrophobe caused stimulation, but those containing lauryl alcohol inhibited growth. Tweens 40 and 60, oleic, linoleic, and linoleic alone, demonstrated no stimulation, but in combination with Tween 40 or Tween 60 showed marked propagation promotion comparable to the effect of Tween 80. In studying growth responses of biochemical mutants of Venturia inaequalis, Lamey et al. (1956) demonstrated that Tween 80 could replace biotin. Of still further interest is the fact that higher concentrations of Tween 80 elicited growth rates much greater than usual for all mutants, even in the presence of an excess of biotin. As suggested by other workers (Williams et al., 1947; Tani and Tatsumi, 1958), this group also indicated a possible growth stimulation due to the fatty acid component of Tween 80. Dubos and Middlebrook (1948) studied the effects on growth of Tween 80 and Triton A-20, which are two water-dispersible, nonionic, surface-active agents which favor dispersed growth of tubercle bacilli in aqueous media. Although Tween 80 eventually loses its ability to disperse cultures of tubercle bacilli, it increases the yield of growth, probably by supplying oleic acid to the bacilli.

Marwin (1959) tested the ability of 115 surface-active agents to enhance growth of a number of pathogenic human fungi. Of the 115

compounds tested, four were found to accelerate growth. These water soluble nonionic surfactants include Nonisol 100, a polyethylene glycol of lauric acid, and polyethylene glycol 400 monolaurate, a monoester of the glycol and lauric acid. Mulsor 224, another of the growth stimulating compounds, is a long chain fatty acid ester containing ether linkages. Pluronic L-64 is a condensate of ethylene oxide with a hydrophobic base. Marwin (1962) provided additional experimental data on growth stimulation by surfactants. Three of the growth stimulating surfactants reported previously were tested on additional fungi; definite stimulation of growth was apparent.

## Foliar Effects of Surfactants

Inherent phytotoxicity of surfactants was reported as early as 1890. Gillette (1890) found that as much as one-twentieth of the leaf surface of plum was destroyed when sprayed with a four-ounce-per-gallon concentration of whale oil. Cory and Langford (1935), evaluating the use of sulfonated alcohols in insecticides, found an inherent phytotoxicity of these materials to several species of plants. Snapdragons withstood a one percent solution of commercial grade sodium lauryl sulfate while chrysanthemums were injured by a 0.25 percent solution. In general, sodium oleyl sulfate was slightly more injurious to foliage than sodium lauryl sulfate. Gast and Early (1956) determined the toxicity of several emulsifiers and solvents to leaves of corn, cucumber, cotton, lima bean, tobacco, and tomato. Since composition and purity were, in most cases not known, these workers were not able to generalize on the relation of chemical structure to the phytotoxicity. In general, the better emulsifiers

were the more phytotoxic. Comparable toxicity effects on roots were observed with approximately one-tenth the concentrations used on leaves. With foliar applications, the most susceptible plant was cucumber, the least sensitive tobacco; tomato, corn, cotton and lima bean were intermediate. Tomato roots were more susceptible to injury than tobacco roots.

Furmidge (1959a) studied the phytotoxicity of several anionic, cationic and nonionic surfactants to leaves of apple and plum. The ionic surfactants tended to be more toxic than the nonionics. This was confirmed by Furmidge (1959b). The anionics produced similar effects on both plum and apple leaves, while the cationics were considerably more toxic to the plum than to the apple leaves. Attempts to correlate the concentration at which phytotoxicity occurred and critical micelle concentration were only partially successful. Good agreement was obtained with two of the anionic materials used; however, with one anionic and the cationic materials, correlations were not evident. No correlation between the surface tensions of the solutions and the degree of damage produced was detected. There was little difference noted between the apparent damage produced on the old as compared with the young leaves. Trees markedly deficient in nitrogen and magnesium sustained greater damage with anionics and nonionics than correspondingly healthy trees. Behavior of cationic materials on mineral-deficient trees was similar to healthy trees. Although temperature and humidity appeared to have little effect on the final amount of damage, the rapidity of action of the surfactants was greater under conditions of high temperature and low humidity.

Daines et al. (1957) reported that an isooctylphenol ethylene oxide condensate was toxic to bean leaves. An increase in concentration up to

4 percent gave a corresponding increase in plant injury. Maximum reduction in surface tension of solutions occurred with the 0.5 percent concentration.

Temple and Hilton (1963) showed a wide variation in the minimum concentration of surfactant necessary to cause death of cucumbers. They stated that, in general, cationic surfactants were the most phytotoxic, nonionics intermediate, and anionics lowest in phytotoxicity, especially those based on alkyl aryl sulfonates. At toxic concentrations, wilting, followed by necrosis, occurred in a few hours; while untreated portions of the plant and the roots remained turgid for at least a day. The apical meristem, which was particularly susceptible up to the fourth-leaf stage, often sustained permanent injury. Appearance of supplemental growing points in axils of injured plants occurred in more mature plants, in which cases recovery of borderline treatments were usually more likely.

## Relation of Structure to Activity

In general, there is an increase in surface activity within a series of chemically-related surfactants when the hydrophobic group is increased in size, while the hydrophilic group remains unchanged (Work and Work, 1948). This occurs until a limiting size is reached. Beyond this limit, water solubility decreases rapidly and micelles are formed. It is suggested that up to the point of micelle formation, activity would be expected to increase with increasing chain length.

Valko and DuBois (1944, 1945) found that the chain length of the alkyl group of aliphatic dimethyl-benzyl ammonium chloride greatly influenced the bactericidal effectiveness; a maximum potency occurring with

a dodecyl or tetradecyl chain. This optimum length is also related to other alkyl groups within the molecule and the nature of the other atoms. Valko and DuBois (1945) showed further that in the alkyl dimethyl-allyl ammonium bromides, maximum bactericidal potency was reached with an alkyl group of 14 to 16 carbons. Introduction of an unsaturated carbon bond had no effect on the minimum bactericidal concentration as was evidenced with the aliphatic dimethyl benzyl ammonium chlorides. In a study of the effects of unsaturation in the hydrocarbon group of aliphatic pyridinium salts, Damodaran (1953) found that bactericidal potency increases with the degree of unsaturation in the long chain hydrocarbon radical of the cation.

Bacterial respiration as influenced by homologous series of alkyl sulfates and alkyl sulfoacetates was studied by Baker et al. (1941). These investigators found that the most active inhibition is exerted by the alkyl sulfates when the hydrophobic group consists of 12, 14, or 16 carbons. These results were obtained using a concentration of 1:3,000 at pH 5.3 and pH 8.0. Sulfoacetate containing a $C_{12}$ alkyl group at a concentration of 1:30,000 was inhibitory at pH 5.3.

In most cases, pH was critical for inhibition, with maximum activity expressed at the lower pH values, especially with the alkyl sulfoacetates. None of the alkyl sulfates or the alkyl sulfoacetates inhibited respiration of the gram-negative organism, E. coli, even at an acid pH. Lauryl esters of amino acids were used in studying the effect of increasing chain length of the hydrophilic portion of the molecule of a cationic series of surfactants. At 1:3,000 concentration, inhibition of bacterial respiration was essentially complete; at 1:30,000 concentration, activity

was enhanced by an increase in length of the amino acid portion of the molecule. In general, the cationic detergents were more effective inhibitors of respiration than were the anionic detergents. Stimulation of respiration at concentrations lower than inhibiting values has been found more commonly among the anionic detergents.

Cornforth et al. (1955) found that anti-tuberculous activity within a series of nonionic polyoxyethylene ethers depended upon the length of the polyoxyethylene chain. Derivatives were most active when the average chain length consisted of 10 to 20 ethylene oxide units; when chain length consisted of 45 to 90 units, tuberculous activity actually was enhanced.

Dills and Menusan (1935) sprayed various plants with fatty acids and their potassium soaps. Capric and lauric acid were more toxic than were either longer or shorter chain fatty acids. In the case of the respective soap, plant injury decreased as the size of the soap molecule increased.

Van Overbeek and Blondeau (1954) investigated the effects of aliphatic acids on the permeability of beet tissues and the effect of hydrocarbons on corn coleoptiles. Toxicity was greatest when the molecular weight of the acids was lowest. Toxicity was greatly enhanced when the aliphatic acids were dissolved in a nonoxidized oil. With maize coleoptiles, these workers concluded that hydrocarbons of smaller molecular weight were more active in disruption of the plasma membrane than were hydrocarbons of a high molecular weight. These results are in agreement with earlier studies by Havis (1950), who demonstrated that aromatics were more toxic than paraffins.

Kaminski (1963) studied the effects of a series of sodium alkyl sulfates containing 8 to 18 carbon chains on penicillinase synthesis and activity in Staphylococcus aureus 6797 PNR. Growth was not inhibited appreciably by the surfactants at 0.0001 percent concentration with the exception of the dodecyl and octadecyl sulfate. Enzymatic activity decreased as the number of carbons in the alkyl chain was increased. The same pattern of inhibition occurred when the detergent concentration was increased 100X. Penicillinase induction exhibited a similar pattern; i.e., markedly inhibited and in some cases stopped completely with $C_{12}$, $C_{14}$, and $C_{17}$ derivatives. A decrease in penicillinase synthesis that occurred with the use of alkyl sulfates with an increasing alkyl chain agreed with the conclusion of Steinhardt et al.; that as the alkyl chain increased in length within a homologous series of anionic detergents, there was an increase in the anionic affinity.

Work and Work (1948) make the generalization that gram-negative organisms are more resistant to the bactericidal effect of anionic detergents than are gram-positive organisms; however, both groups are susceptible to cationic detergents. The differential sensitivity is thought to be a failure of anionic detergents to pass through the plasma membrane of gram-negative organisms. They further state that the enzyme systems of E. coli are resistant to the inhibitory action of anionic surface-active agents but enzyme preparations made by grinding the cells demonstrated the same degree of sensitivity as did enzymes in an intact cell of a gram-positive organism. Ponder (1946) suggested a neutralization of the lytic effect of some surface-active materials. Baker et al. (1941) have shown that the phospho-lipid layer may protect cells against detergents.

Lovelock (1954) and Lovelock and Rees (1955) have noted a relationship between release of cholesterol and phospholipid and lysis of erythrocytes by anionic surfactants. These workers and Hodes et al. (1961) noted that hydrocarbon chain length was the structure best correlated with activity.

Furmidge (1959b) found, in studying the phytotoxicity to apples of foliar applications of surfactants, an increase with increase in size of the alkyl group from butyl to 5-ethyl hexyl of sodium dialkyl sulfosuccinates. A further increase in size of the alkyl group resulted in decreased phytotoxicity. With plums, the maximum phytotoxicity occurred with a dihexyl alkyl group. It was further shown that a N-octyl material was less toxic than the branched octyl derivative. Alkyl trimethyl ammonium bromides showed a progressive decrease in phytotoxicity as the alkyl group was increased from 12 to 20 carbons. Alkyl dimethyl ethyl ammonium ethyl sulfates, alkyl pyridinium chlorides, and bromides were comparable to the alkyl-trimethyl ammonium bromides. Although the non-ionics were only slightly phytotoxic, maximum damage occurred as the length of the ethylene oxide chain was increased; maximum potency occurred when enough ethylene oxide groups were present to make the condensate just soluble in water.

# MATERIALS AND METHODS

Commercially-available surfactants representing all ionogenic classes were obtained from their respective manufacturers. In several experiments, a number of surfactants of similar composition were chosen within a single family. Technical data were obtained either from brochures provided by the respective companies or from "Detergents and Emulsifiers" (McCutcheon, Inc., 1962). In some cases, information was supplemented by communication with appropriate manufacturers. The surfactants used in this study are catalogued in Table 1. Surfactants were used at concentrations ranging from 0.01 percent to 5.0 percent. Percentages were based on active ingredient when known, and when percent active ingredient was unknown, concentration was based on commercial material. Distilled water was used as the solvent or dilutent in all cases. The various surfactants were evaluated on the basis of the observed responses of selected plant tissues.

## Action of Surfactants on Germination

The effects of surfactants on germination were determined using corn, Zea mays line Wf9Tms x B37; oats, Avena sativa var. Cherokee; radishes, Raphanus sativus var. Scarlet Globe; and giant foxtail, Seteria faberii. Fifteen to twenty-five seeds, depending on species tested, were distributed on a single sheet of filter paper placed in the bottoms of standard-size petri plates, 9 cm. in diameter. The surfactant solutions or mixtures were added in the following amounts: corn and oats, 5 ml. per dish; radish, 4 ml. per dish; and giant foxtail, 3 ml. per dish.

Table 1. Trade names and a summary of the relevant physical and chemical properties of the surfactants used in this investigation

| Trade name | Molecular weight | Chemical Composition | Percent active ingredient | Ionogenic class |
|---|---|---|---|---|
| Triton[1] X-15 | 272 | Octyl phenyl polyethoxy ethanol | 99 | Nonionic |
| Triton X-35 | 338 | Octyl phenyl polyethoxy ethanol | 99 | Nonionic |
| Triton X-45 | 426 | Isooctyl phenyl polyethoxy ethanol | 99 | Nonionic |
| Triton X-100 | | Isooctyl phenyl polyethoxy ethanol | 99 | Nonionic |
| Triton X-102 | 756 | Isooctyl phenyl polyethoxy ethanol | 99 | Nonionic |
| Triton X-114 | 536 | Isooctyl phenyl polyethoxy ethanol | 99 | Nonionic |
| Triton X-165 | 910 | Octyl phenyl polyethoxy ethanol | 70 | Nonionic |
| Triton X-205 | 1,086 | Octyl phenyl polyethoxy ethanol | 70 | Nonionic |
| Triton X-305 | 1,526 | Octyl phenyl polyethoxy ethanol | 70 | Nonionic |
| Triton N-57 | 440 | Nonyl phenyl polyethoxy ethanol | 99 | Nonionic |
| Triton N-101 | 630 | Nonyl phenyl polyethoxy ethanol | 99 | Nonionic |
| Triton N-128 | 814 | Nonyl phenyl polyethoxy ethanol | 99 | Nonionic |
| Triton B-1956 | | Modified phthalic glycerol alkyd resin | 77 | Nonionic |
| Hyamine[1] 2389 | 331 | 40 percent methyl dodecetyl benzyl trimethyl ammonium chloride, 10 percent methyl dodecetyl xylylene bis trimethyl ammonium chloride, 50 percent HOH | 50 | Cationic |
| Surfactant[1] DN-65 | | Modified ethoxylated straight chain alcohol | 100 | Nonionic |

[1]Rohm & Haas Company, Philadelphia, Pennsylvania.

Table 1. (Continued)

| Trade name | Molecular weight | Chemical composition | Percent active ingredient | Ionogenic class |
|---|---|---|---|---|
| Ultrawet[2] DS | Medium | Alkyl aryl benzene sodium sulfonate | 90 | Anionic |
| Ultrawet 30DS | Medium | Alkyl aryl benzene sodium sulfonate | 25 | Anionic |
| Ultrawet K | High | Alkyl aryl benzene sodium sulfonate | 90 | Anionic |
| Ultrawet SK | | Alkyl aryl benzene sodium sulfonate | 40 | Anionic |
| Igepal[3] Co-630 | | Nonylphenoxypoly (ethyleneoxy) ethanol | 99 | Nonionic |
| Igepal Co-730 | | Nonylphenoxypoly (ethyleneoxy) ethanol | 99 | Nonionic |
| Igepal Co-850 | | Nonylphenoxypoly (ethyleneoxy) ethanol | 99 | Nonionic |
| Igepal Co-890 | | Nonylphenoxypoly (ethyleneoxy) ethanol | 99 | Nonionic |
| Igepal Co-970 | | Nonylphenoxypoly (ethyleneoxy) ethanol | 99 | Nonionic |
| Igepal Co-990 | | Nonylphenoxypoly (ethyleneoxy) ethanol | 99 | Nonionic |
| Tergitol[4] 4 | | Sodium sulfate derivate of 7 ethyl, 2 methyl, 4 undecanol | 26-28 | Anionic |
| Tergitol 7 | | Sodium sulfate derivate of 3,9 diethyl tridecanol-6 | 25 | Anionic |
| Tergitol 08 | | Sodium sulfate derivate of ethyl-1-hexanol | | |
| Tergitol NP-33 | | Nonyl phenyl polyethylene glycol ether | 100 | Nonionic |

[2]Atlantic Refining Company, Chicago, Illinois.

[3]Anatara Chemicals, New York, New York.

[4]Union Carbide Corporation, New York, New York.

Table 1. (Continued)

| Trade name | Molecular weight | Chemical composition | Percent active ingredient | Ionogenic class |
|---|---|---|---|---|
| Tergitol TMN | | Trimethyl nonly polyethylene glycol ether | 90 | Nonionic |
| Tergitol P-28 | | Sodium di(2 ethyl hexyl) phosphate | 24-26 | Anionic |
| Ethomeen[5] 18/25 | | Tertiary amines; ethylene oxide condensation (source of alkyl radical - stearyl amine) | 100 | Cationic |
| Ethomeen 0/15 | | Products of the primary fatty amines; (source of alkyl radical - oleyl amine) | 100 | Cationic |
| Ethomeen T/12 | 350 | Products of the primary fatty amines; (source of alkyl radical - tallow amine) | 100 | Cationic |
| Ethomeen T/15 | 482 | Products of the primary fatty amines; (source of alkyl radical - tallow amine) | 100 | Cationic |
| Ethomeen 18/15 | 495 | Products of the primary fatty amines; (source of alkyl radical - stearyl amine) | 100 | Cationic |
| Ethomeen 18/60 | 2,470 | Products of the primary fatty amines; (source of alkyl radical - stearyl amine) | 100 | Cationic |

[5]Armour Industries Chemical Company, Chicago, Illinois.

Table 1. (Continued)

| Trade name | Molecular weight | Chemical composition | Percent active ingredient | Ionogenic class |
|---|---|---|---|---|
| Ethomid[5] 0/15 | 500 | Ethylene oxide condensates of fatty acid amides (source of alkyl radical-oleyl amide) | 100 | Nonionic |
| Ethomid HT/60 | 2,478 | Ethylene oxide condensates of fatty acid amides (source of alkyl radical-hydrogenated tallow amide) | 100 | Nonionic |
| Ethoquad[5] C/12 | 353 | Polyethoxylated quarternary ammonium salts (source of alkyl radical - coco fatty acid) | 100 | Cationic |
| Ethoquad 0/12 | 416 | Polyethoxylated quarternary ammonium salts (source of alkyl radical - oleic fatty acid) | 100 | Cationic |
| Ethoquad 18/12 | 422 | Polyethoxylated quarternary ammonium salts (source of alkyl radical - stearic fatty acid) | 100 | Cationic |
| Tetronic[6] 304 | 1,700 | Compounds formed by sequential addition of propylene and ethylene oxides to ethylenediamine | 100 | Nonionic |
| Tetronic 701 | 3,400 | Compounds formed by sequential addition of propylene and ethylene oxides to ethylenediamine | 100 | Nonionic |

[6]Wyandotte Chemicals Corporation, Wyandotte, Michigan.

Table 1. (Continued)

| Trade name | Molecular weight | Chemical composition | Percent active ingredient | Ionogenic class |
|---|---|---|---|---|
| Tetronic[6] 704 | 5,400 | Compounds formed by sequential addition of propylene and ethylene oxides to ethylenediamine | 100 | Nonionic |
| Tetronic 707 | 12,000 | Compounds formed by sequential addition of propylene and ethylene oxides to ethylenediamine | 100 | Nonionic |
| Tetronic 908 | 27,000 | Compounds formed by sequential addition of propylene and ethylene oxides to ethylenediamine | 100 | Nonionic |
| Pluronic[6] F-38 | 4,700 | A condensate of ethylene oxide with a hydrophobic base formed by condensing propylene oxide with propylene glycol. | 100 | Nonionic |
| Pluronic F-68 | 8,700 | A condensate of ethylene oxide with a hydrophobic base formed by condensing propylene oxide with propylene glycol. | 100 | Nonionic |
| Pluronic F-88 | 11,000 | A condensate of ethylene oxide with a hydrophobic base formed by condensing propylene oxide with propylene glycol. | 100 | Nonionic |
| Pluronic F-98 | 13,000 | A condensate of ethylene oxide with a hydrophobic base formed by condensing propylene oxide with propylene glycol. | 100 | Nonionic |
| Pluronic F-108 | 16,300 | A condensate of ethylene oxide with a hydrophobic base formed by condensing propylene oxide with propylene glycol. | 100 | Nonionic |

Table 1. (Continued)

| Trade name | Molecular weight | Chemical composition | Percent active ingredient | Ionogenic class |
|---|---|---|---|---|
| Emcol[7] HA | | Complex sulfonate | | Anionic |
| Emcol HB | | Complex sulfonate | | Anionic |
| Emcol HC | | Complex sulfonate | | Anionic |
| Toximul[8] R | | Sulfate-nonionic blend | | |
| Toximul S | | Sulfate-nonionic blend | | |
| Carbowax[4] 300 | 285-315 | Polyethylene glycol | | |
| Carbowax 400 | 380-420 | Polyethylene glycol | | |
| Carbowax 600 | 570-630 | Polyethylene glycol | | |
| Solulan[9] 25 | | Ethoxylated lanolin alcohol | 100 | Nonionic |
| Solulan 75 | | Ethoxylated lanolin | 100 | Nonionic |
| Solulan 98 | | Acetylated polyoxyethylene derivatives of lanolin | 100 | Nonionic |
| Solulan C-24 | | Polyoxyethylene cholesterol | 100 | Nonionic |
| Solar[10] NP Liquid | 638 | Ethyoxylated nonyl phenol | 100 | Nonionic |
| Solar NPO | | Ethyoxylated nonyl phenol | 100 | Nonionic |

[7]Witco Chemical Company, Inc., Chicago, Illinois.

[8]Stepan Chemical Company, Northfield, Illinois.

[9]American Cholesterol Products, Inc., Edison, New Jersey.

[10]Swift and Company, Chicago, Illinois.

Table 1. (Continued)

| Trade name | Molecular weight | Chemical composition | Percent active ingredient | Ionogenic class |
|---|---|---|---|---|
| Solar[10] NP-100 | | Ethoxylated octyl phenol | 100 | Nonionic |
| Solar #15 | | Ethoxylated nonyl phenol | 100 | Nonionic |
| Tween[11] 20 | | Polyoxyethylene sorbitan monolaurate | 100 | Nonionic |
| Tween 40 | | Polyoxyethylene sorbitan monopalmitate | 100 | Nonionic |
| Tween 60 | | Polyoxyethylene sorbitan monosterate | 100 | Nonionic |
| Tween 80 | | Polyoxyethylene sorbitan monooleate | 100 | Nonionic |
| Tween 85 | | Polyoxyethylene sorbitan trioleate | 100 | Nonionic |
| Emulsynt[12] 219 | | Polyoxyethylene glycol laurate | 100 | Nonionic |
| Emulsynt 224 | | Polyoxyethylene glycol laurate | 100 | Nonionic |
| Emulsynt 225 | | Polyoxyethylene glycol laurate | 100 | Nonionic |
| Emulsynt 610A | | Polyoxyethylene glycol laurate | 100 | Nonionic |
| Nonisol[13] 100 | | Polyethylene glycol 400 monolaurate | 100 | Nonionic |
| Nonisol 110 | | Polyethylene glycol 400 dilaurate | 100 | Nonionic |
| Nonisol 200 | | Polyethylene glycol 400 monooleate | 100 | Nonionic |
| Nonisol 210 | | Polyethylene glycol 400 dioleate | 100 | Nonionic |
| Nonisol 250 | | Polyethylene glycol 1000 monolaurate | 100 | Nonionic |
| Nonisol 300 | | Polyethylene glycol 400 monosterate | | |

[11]Atlas Powder Company, Wilmington, Delaware.

[12]Van Dyk and Company, Belleville, New Jersey.

[13]Geigy Chemical Corporation, Yonkers, New York.

Table 1. (Continued)

| Trade name | Molecular weight | Chemical composition | Percent active ingredient | Ionogenic class |
|---|---|---|---|---|
| Alrosol[13] | | Coco diethanolamide | 87 | Nonionic |
| Alrosol B | | Vegetable grade coco diethanolamide | 100 | Nonionic |
| Alrosol C | | Capric acid diethanolamide | 100 | Nonionic |
| Alrosol O | | Oleic acid diethanolamide | 100 | Nonionic |
| Alrosol S | | Stearic acid diethanolamide | 100 | Nonionic |
| Alkanol[14] OA | 313 | Long chain alcohol ethylene oxide condensate | 99 | Nonionic |
| Alkanol OJ | 687 | Long chain alcohol ethylene oxide condensate | 99 | Nonionic |
| Alkanol OP | | Long chain alcohol ethylene oxide condensate | 99 | Nonionic |
| Alkanol HC | 1,127 | Long chain alcohol ethylene oxide condensate | 99 | Nonionic |
| Alkanol HCS | 1,127 | Long chain alcohol ethylene oxide condensate | 99 | Nonionic |
| Deriphat[15] 151 | | Sodium N-coco aminopropionate | 100 | Amphoteric |
| Deriphat 154 | | Disodium N-tallow iminodipropionate | 100 | Amphoteric |
| Deriphat 160 | | Disodium N-lauryl iminodipropionate | 100 | Amphoteric |
| Deriphat 160C | | Partial sodium salt of N-lauryl imino-dipropionic acid | 30 | Amphoteric |

[14]E. I. DuPont De Nemours and Company, Wilmington, Delaware.

[15]General Mills, Chemical Division, Kankakee, Illinois.

Table 1. (Continued)

| Trade name | Molecular weight | Chemical composition | Percent active ingredient | Ionogenic class |
|---|---|---|---|---|
| Deriphat[15] 151C | | N-coco amino propionic acid | 45 | Amphoteric |
| Deriphat 170C | | N-lauryl myristyl aminopropionic acid | 50 | Amphoteric |
| Alrodyne[13] 315 | | Polyethylene glycol fatty esters | 100 | Nonionic |
| Alrodyne 6104 | | Polyethylene glycol fatty esters | 100 | Nonionic |
| Miranol[16] DM | 450 | 4,5-dihydro-1(4)-2-heptadecyl-1-(2 hydroxyethyl)-1-(sodium carboxymethyl)-1,3-diazolium hydroxide | 21 | Amphoteric |
| Miranol CM | 388 | 4,5-dihydro-1(4)-2-hendecyl-1-(2 sodium hydroxyethyl)-1-(sodium carboxy methyl)-1,3-diazolium hydroxide (coconut derivative | 37 | Amphoteric |
| Miranol HM | 378 | 4,5-dihydro-1(4)-2-hendecyl-1-(2 sodium hydroxyethyl)-1-(sodium carboxy methyl)-1,3-diazolium hydroxide (pure lauric acid derivative) | 37 | Amphoteric |
| Sole-Fonate[17] 104 | | Sodium salt of dodecylbenzene sulfonate | 44 | Anionic |
| Sole-Fonate 98K | | Dodecyl benzene sulfonic acid | 94 | Anionic |

[16]Miranol Chemical Company, Irvington, New Jersey.

[17]Sole Chemical Company, Chicago, Illinois.

Table 1. (Continued)

| Trade name | Molecular weight | Chemical composition | Percent active ingredient | Ionogenic class |
|---|---|---|---|---|
| Sulfanole[18] FAF | | Sodium salt of an alcohol sulfate | 30 | Anionic |
| Sulfanole KA | | Alkyl aryl amine sulfonate | 60 | Anionic |
| Surfactant[14] WK | | Dodecyl ether of polyethylene glycol | 90 | |
| Sterox[19] SK | | Polyoxyethylene thioether | 100 | Nonionic |
| Emulsifying[14] Agent A | | Amine salts of alkyl and alkyl aryl sulfonates | 89 | |
| Superamide[20] GR | | Refined coconut fatty acid diethanolamine condensate | 80 | Nonionic |
| Tetrosan[20] 3,4-D | | Alkyl dimethyl-3,4-dichlorobenzyl ammonium chloride | 60 | Cationic |
| Sorbit[13] P | | Mixed N-butyl sodium naphthalene sulfonates | 65 | Anionic |
| Alrowet[13] D-65 | 444 | Sodium dioctyl sulfosuccinate | 65 | Anionic |

[18]Warwick Chemical Company, New York, New York.

[19]Monsanto Company, Saint Louis, Missouri.

[20]Onyx Chemical Corporation, Jersey City, New Jersey.

Table 1. (Continued)

| Trade name | Molecular weight | Chemical composition | Percent active ingredient | Ionogenic class |
|---|---|---|---|---|
| Diasyl[13] L | 316 | Lauryl iminodiacetic acid | 100 | Anionic |
| Cetyl pyridinium chloride[21] | 358 | Cetyl pyridinium chloride | 100 | Cationic |
| Cetol[21] | | Cetyl dimethyl benzyl ammonium chloride | 100 | Cationic |

[21]Fine Organics, Inc., Lodi, New Jersey.

Each treatment was replicated at least 3 times. The corn, radish, buttonweed, and foxtail seeds were germinated under alternating temperatures of 20°C. and 30°C. (15 hours at 20°C., dark, and 9 hours at 30°C., light). Oats were germinated at 20°C. (12 hours light and 12 hours dark). Numbers of seeds germinating were recorded 7 days after placing them in the germinators. Germination was defined, for the purposes of this study, as that stage of growth when the radicle had penetrated the seed coat and was approximately 5 mm. or more in length.

## Action of Surfactants on Root Elongation

Effects of surfactants on elongation of the primary root of corn were determined using standard petri dishes, 9 cm. in diameter. Corn seeds were first germinated by placing them in rows (embryo up) between wet paper towels. The seeds were then placed in a 30°C. chamber in the dark and left to elongate; seedlings were used for tests when elongated radicles averaged 2 to 3 cm. in length.

For each treatment, 3 seedlings were selected, measured, and placed on a filter paper in the bottom of a petri dish. Five ml. of each test material concentration was added to the appropriate dish. Treated seedlings were placed in 30°C. chambers in the dark. Growth of radicles was measured after 24, 48, and 72 hours.

## Foliar Treatments with Surfactants on Soybeans

Soybean plants were grown under ambient greenhouse conditions in 4-inch pots filled with potting soil. Foliar phytotoxicity of several

surfactants was determined by treating soybean seedlings at the unifoliate stage with varying concentrations of surfactants in distilled water.

The aerial portions above the cotyledons were immersed in the surfactant solution for 5 seconds. After immersion, the plants were inverted and the excess solution was allowed to drain thoroughly from the foliage. Each treatment was replicated three times. All treatments were carried out during the afternoon when there was bright sunlight.

Plants were observed 48 hours after treatment. Leaf injury was estimated with a 5-point injury rating scale: 0, no effect; 1, slightest, discernible injury; 2 and 3, lower and higher levels of injury; 4, death of tissue which came in contact with the surfactant solution; and 5, death of entire plant. The range of injury observed is illustrated in Figure 1. After 14 days, growth of plants above the unifoliate was harvested, dried for 48 hours at 100°C., and then weighed.

### Effect of Surfactants on Permeability of Beet Tissue

Effects of surfactants on permeability were determined using tissue from the enlarged root of red beet (Beta vulgaris). A size 3 cork borer was used to remove cores of beet tissue which were placed in distilled water immediately. From each core sections approximately 1.0 mm. were made using a hand microtome. Sections were placed in a wire-covered beaker and washed in running distilled water for 60 seconds. Five washed sections were placed in 5 ml. of either 0.0, 0.01, 0.05, 0.1, 0.5, 1.0, or 5.0 percent surfactant solution contained in a 10 ml. beaker. Sections were dispersed in the solutions so that each section was exposed equally to the surfactant solution. After 27 minutes, the solution was poured

Figure 1. Soybean plants illustrating the five points used in the injury rating scale

into matched cuvettes and the percent transmission determined with a Bausch & Lomb Spectronic 20 colorimeter at 538mμ. Identical surfactant solutions were used as the comparison cuvettes. Each treatment was replicated 3 times.

Additional experiments included time as a variable. Treatments were the same as previously described, except that percent transmission of the solution was determined at the end of 3, 9, 18, and 27 minutes. After each determination, the solution was returned to the beaker containing the original tissue.

### Effects of Surfactants when Applied as Soil Treatments

To study the effect of surfactants as soil applications, 5-inch clay pots were filled with potting soil and seeded with oat seeds. Surfactants, at rates of 0, 64, 192, and 318 gallons per acre, were applied in a total volume of 100 ml. per pot. After growing under ambient greenhouse conditions for 21 days, the above-ground foliage was harvested, dried for 48 hours at 100°C., and then weighed. Each treatment was replicated 3 times.

### Effect of Surfactants on Soybeans Grown in Water Culture

Soybeans were grown in sterilized sand and until just before emergence of the first trifoliate leaf, then the roots were washed free of sand and the plants transferred to aluminum-foil-covered jars. Plants were grown in a basic nutrient solution according to Hoagland and Arnon (1950), to which was added enough surfactant to result in a 0.0, 0.01, 0.1, and 1.0 percent solution. Solutions were replenished as needed. Plants were grown under ambient greenhouse conditions for 21 days, after

which plant parts above the cotyledons were cut off, dried at 100°C. for 48 hours, and then weighed.

## Effects of Some Selected Surfactants on the Microstructure of Soybean Tissue

From soybean plants grown in the greenhouse, disks of tissue were taken from the just emerging first trifoliate leaves with a Trophy hypodermic syringe fitted with a cut-off Yale stainless steel No. 18 needle. A small amount of water was used in the syringe to facilitate handling the leaf disks. Immediately after taking the disks, they were placed in small beakers containing the appropriate test solution. Treatments were carried out at 25°C., for the prescribed periods of time.

After treatment, tissue was fixed in 6.5 percent glutaric dialdehyde in 0.067M $PO_4$ buffer at pH 7.3. $PO_4$ buffer, pH 7.3, was prepared by balancing 0.067M $KH_2PO_4$ and 0.067M $Na_2HPO_4$ until the desired pH was obtained. Fixation was carried out at 0°C. to 4°C., for 12 to 16 hours. Post-fixation was accomplished using a Palade buffered (7.3) 1 percent osimum tetroxide solution. Fixation was carried out at 0°C. to 4°C., for 1 hour (Palade, 1952). Dehydration was done at room temperature by exposure to increasing concentrations of ethyl alcohol. After dehydration, tissue was washed in propylene oxide, using 5 changes and 5-minute exposure periods between changes. Infiltration was accomplished by using increasing amounts of 3:2 Epon 812 (Luft, 1961) in propylene oxide. To catalyze polymerization, 2,4,6-tri(dimethyl aminomethyl) phenol (DMP) was included. Tissue was placed in fresh 3:2 Epon and rotated overnight on a mechanical rotor. Embedding was accomplished using the same Epon, and

aluminum boats prepared from medium-weight aluminum foil. Polymerization was carried out at 35°C., for 24 hours; 45°C., for 24 hours; and 5 to 7 days at 60°C.

Sections 40 to 90 mμ thick were made using a DuPont diamond knife and a LKB ultramicrotome. Sections were picked up either on cleaned 400-mesh copper grids or on formvar-coated 150-mesh copper grids. Uranyl acetate methanol (Stempak and Ward, 1964) or lead salts (Millonig, 1961; Karnovsky, 1961; Watson, 1958; and Norman, 1964) were used to stain the sections. A RCA EMU 3F electron microscope, operated at 50 KV, using an objective aperature of 30 to 40 μ in diameter, was used to study the tissue; micrographs were taken on Kodak contrast plates and developed in Kodak D-19 developer for 4 minutes. Negatives were routinely enlarged 4.2 times on Kodak F-4 Kodabromide paper.

## Measurement of Surface Tension

Surface tension of the various surfactant solutions was determined with a Cenco tensiometer using a 4 cm. platinum ring. Solutions were prepared and allowed to equilibrate at 20°C. Surface tension measurements were made at 20°C., and are expressed as dynes/cm.

# RESULTS

In general, the toxicity patterns demonstrated by the several families of surfactants were similar across the range of tests utilized in this investigation. Within the Igepal Co- surfactants, for example, Co-630, Co-730, and Co-850 were, to varying degrees, inhibitory to germination, reduced the elongation of corn roots, and were toxic to leaves of young soybeans. Other members of the series, Co-890, Co-970, and Co-990, had no appreciable effects when included in the tests enumerated above. There were, however, exceptions to this generalization. Of this series of Igepal surfactants, none increased the permeability of beet tissue cell membranes, as measured in this study.

Toxic and non-toxic are relative terms which are used to denote materials which either kill or inhibit normal plant growth, or those which have little or no measurable effect on plants.

## Experiments with Seeds, Roots and Leaves

Responses of seeds, roots and leaves to surfactants will be presented together, since in most instances the effects on these three plant tissues were comparable. The results obtained with each family of surfactants are presented so as to facilitate comparisons among surfactants having only slight differences in chemical composition.

### Tritons

The results obtained with seeds of corn, oats, radish, and giant foxtail, treated with 5 ml. of various Triton surfactants at 0.0, 0.01, 0.05, 0.1, 0.5, 1.0, and 5.0 percent concentrations, are presented in Table 2.

Table 2. Total number of seeds of corn, oats, radish, and giant foxtail germinating 7 days after treatment with 7 concentrations of selected surfactants from the Triton family; data are counts from 45 seeds, 3 replications of 15 seeds each for corn, oats, and radish; and 75 seeds, 3 replications of 25 seeds each for giant foxtail

| Surfactant | 5 | 1 | .5 | .1 | .05 | .01 | Ck | 5 | 1 | .5 | .1 | .05 | .01 | Ck |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Corn | | | | | | | Oats | | | | | | |
| Triton N-101 | 20 | 20 | 20 | 41 | 43 | 45 | 45 | 0 | 0 | 0 | 1 | 7 | 20 | 40 |
| Triton N-128 | 20 | 12 | 19 | 27 | 38 | 45 | 45 | 0 | 0 | 1 | 5 | 13 | 12 | 42 |
| Triton N-57 | 21 | 16 | 19 | 37 | 38 | 44 | 45 | 0 | 0 | 0 | 3 | 7 | 14 | 41 |
| Triton X-45 | 26 | 12 | 13 | 23 | 45 | 44 | 44 | 0 | 0 | 0 | 0 | 7 | 9 | 42 |
| Triton X-102 | 20 | 23 | 16 | 18 | 30 | 45 | 44 | 0 | 0 | 0 | 5 | 6 | 18 | 40 |
| Triton X-114 | 5 | 11 | 16 | 21 | 44 | 45 | 45 | 0 | 0 | 0 | 1 | 0 | 20 | 38 |
| Triton X-100 | 12 | 8 | 9 | 8 | 30 | 43 | 44 | 0 | 0 | 0 | 0 | 3 | 17 | 40 |
| Triton X-165 | 33 | 37 | 36 | 43 | 45 | 45 | 45 | 0 | 1 | 2 | 21 | 28 | 39 | 37 |
| Triton X-205 | 37 | 42 | 41 | 41 | 42 | 44 | 45 | 9 | 7 | 12 | 13 | 11 | 25 | 40 |
| Triton X-305 | 41 | 43 | 45 | 42 | 44 | 45 | 45 | 15 | 14 | 17 | 22 | 29 | 39 | 34 |
| | Radish | | | | | | | Giant Foxtail | | | | | | |
| Triton N-101 | 30 | 44 | 44 | 44 | 45 | 45 | 45 | 0 | 40 | 58 | 56 | 64 | 66 | 71 |
| Triton N-128 | 30 | 29 | 38 | 39 | 33 | 38 | 38 | 41 | 49 | 62 | 62 | 55 | 62 | 67 |
| Triton N-57 | 42 | 43 | 44 | 41 | 40 | 40 | 45 | 52 | 63 | 59 | 67 | 55 | 61 | 63 |
| Triton X-45 | 40 | 36 | 31 | 41 | 41 | 40 | 38 | 13 | 54 | 58 | 57 | 59 | 63 | 65 |
| Triton X-102 | 5 | 19 | 22 | 32 | 34 | 34 | 39 | 34 | 55 | 54 | 57 | 55 | 61 | 64 |
| Triton X-114 | 1 | 26 | 26 | 44 | 45 | 45 | 44 | 0 | 47 | 46 | 65 | 61 | 64 | 61 |
| Triton X-100 | 0 | 21 | 29 | 45 | 45 | 45 | 45 | 5 | 23 | 42 | 48 | 53 | 44 | 59 |
| Triton X-165 | 37 | 45 | 44 | 45 | 45 | 45 | 45 | 60 | 59 | 63 | 63 | 62 | 63 | 59 |
| Triton X-205 | 43 | 43 | 41 | 44 | 43 | 44 | 44 | 42 | 55 | 54 | 38 | 51 | 60 | 51 |
| Triton X-305 | 45 | 44 | 44 | 44 | 44 | 44 | 45 | 66 | 68 | 61 | 67 | 69 | 66 | 65 |

Each datum represents the total number of seeds which germinated from 3 replications. Seeds treated with surfactants of the Triton series demonstrated varying degrees of both toxic and non-toxic responses. Generally, the materials containing the octyl phenol hydrophobe were more toxic than those containing a nonyl phenol hydrophobe when both contained equal numbers of polyoxyethylene groups. Toxicity decreased as the number of

polyoxyethylene groups per mole increased. Oats were the most sensitive and corn the least sensitive; radish and giant foxtail were intermediate in sensitivity. The observed response pattern of corn roots to the Triton surfactants, summarized in Table 3, was similar to that observed in germination studies. Toxicity decreased appreciably as the content of polyoxyethylene per mole increased, as shown in Figure 2. Studies with pairs of materials which contained equal amounts of polyoxyethylene, but had either an octyl phenol or nonyl phenol hydrophobe, confirmed the earlier generalization that the octyl phenol hydrophobe derivatives were more toxic. These observations are supported by analyses of variance in Tables 4, 5, and 6, and Figures 3, 4, and 5. Two members of the series, X-15 and X-35, which contained only 1 and 3 polyoxyethylene groups per mole respectively, were less toxic than members of the series containing 5 to 15 moles of polyoxyethylene. Triton X-305, which contained the longest polyoxyethylene chain of any member of the series, had no effect on the elongation of the corn roots.

Foliar responses of soybean plants exposed to various concentrations of Triton surfactants are presented in Tables 7 and 8. Among the Tritons, the patterns of foliar toxicity demonstrated were comparable to those revealed in the germination and root elongation experiments. Concentrations of 0.1 percent or less had no appreciable effect on total yield of dry matter at time of leaf harvest. At the 1.0 percent concentration, there was greater leaf damage with the low molecular weight members of the series. These conclusions are supported in Figures 6, 7, and 8.

Table 3. Elongation of corn roots, in centimeters, measured 3 days after treatment with 7 concentrations of selected surfactants from the Triton family; data are averages of measurements from 3 seedlings

| Surfactant | Concentration 0 | .01 | .05 | .1 | .5 | 1 | 5 |
|---|---|---|---|---|---|---|---|
| N-101 | 19.1 | 14.4 | 15.1 | 12.3 | 5.9 | 3.4 | 1.6 |
| N-128 | 16.6 | 14.2 | 12.4 | 9.5 | 8.8 | 9.5 | 3.7 |
| N-57 | 14.2 | 13.1 | 13.6 | 14.4 | 14.5 | 13.5 | 7.4 |
| X-15 | 15.4 | 15.5 | 15.1 | 14.3 | 13.1 | 12.6 | 4.6 |
| X-35 | 14.7 | 17.0 | 10.5 | 7.2 | 6.9 | 6.8 | 4.1 |
| X-45 | 17.7 | 17.5 | 12.1 | 3.1 | 0.6 | 0.9 | 0.0 |
| X-100 | 15.8 | 15.9 | 10.7 | 7.7 | 0.0 | 0.1 | 0.1 |
| X-102 | 17.1 | 14.8 | 12.4 | 4.6 | 1.9 | 0.4 | 0.4 |
| X-114 | 16.3 | 13.3 | 12.2 | 4.0 | 0.6 | 1.7 | 0.1 |
| X-165 | 18.1 | 15.1 | 17.0 | 15.3 | 11.1 | 10.2 | 6.0 |
| X-205 | 16.5 | 13.1 | 12.9 | 10.5 | 8.8 | 8.7 | 8.5 |
| X-305 | 19.1 | 15.5 | 15.4 | 15.5 | 16.5 | 16.1 | 16.2 |

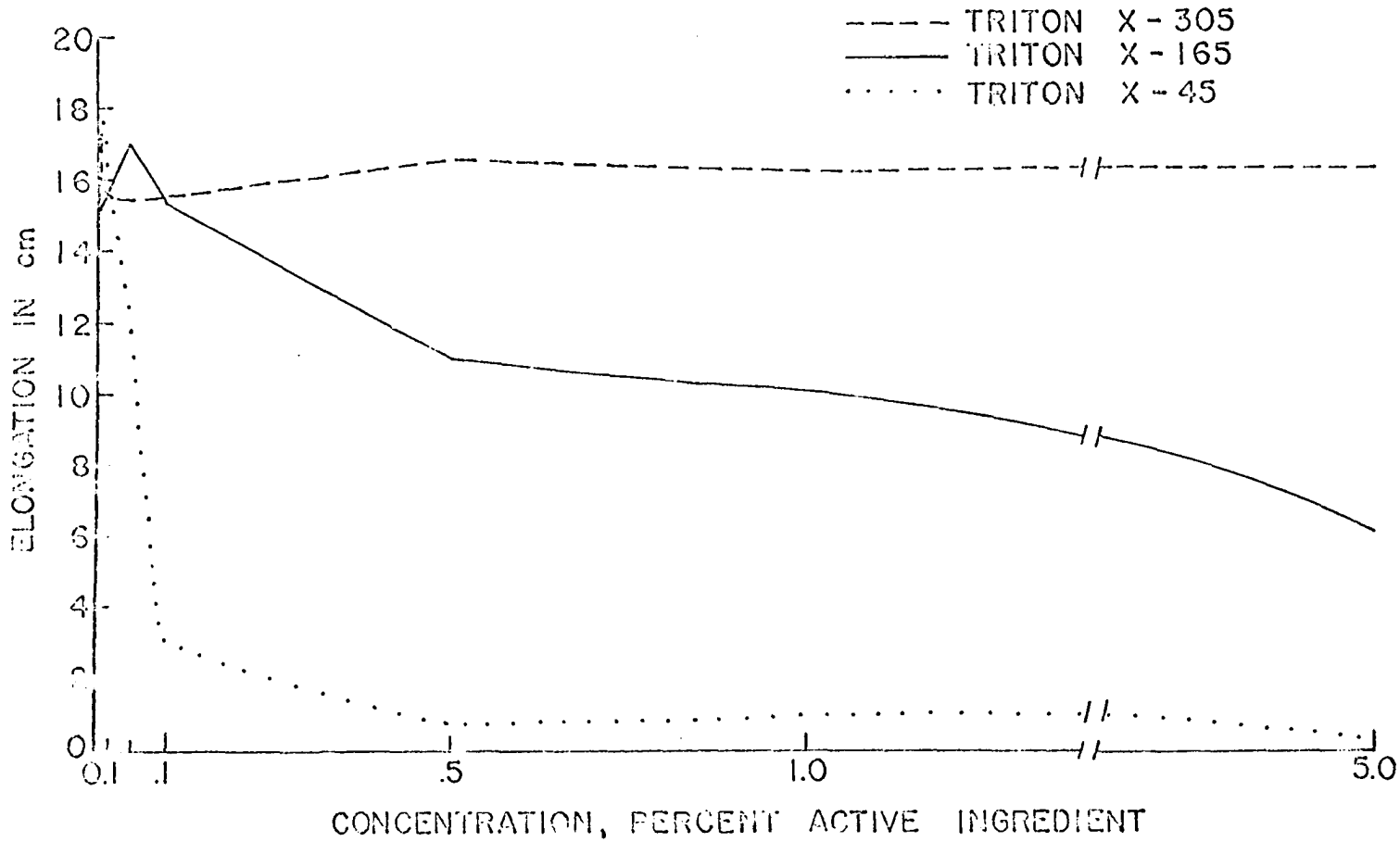



Figure 2. Elongation of corn roots, in centimeters, measured 3 days after treatment with 7 concentrations of selected surfactants from the Triton family; points are averages of measurements from 3 seedlings

Table 4. Analysis of variance for root elongation data taken from corn roots treated with Triton X-100, an octyl phenol derivative, and Triton N-101, a nonyl phenol derivative, at each of 7 concentrations

| Source of variation | df | Sum of squares | Mean square | F values |
|---|---|---|---|---|
| Surfactant | 1 | 70.46 | 70.46 | 19.62** |
| Concentration | 6 | 1610.00 | 268.33 | 74.74** |
| Surfactant x Concentration | 6 | 32.21 | 5.37 | 1.49 |
| Error | 28 | 100.64 | 3.59 | |

**Denotes significant differences at P = 0.01.

Table 5. Analysis of variance for root elongation data taken from corn roots treated with Triton X-45, an octyl phenol derivative, and Triton N-57, a nonyl phenol derivative, at each of 7 concentrations

| Source of variation | df | Sum of squares | Mean square | F values |
|---|---|---|---|---|
| Surfactant | 1 | 501.30 | 501.30 | 99.46** |
| Concentration | 6 | 725.59 | 120.93 | 23.99** |
| Surfactant x Concentration | 6 | 217.39 | 36.23 | 6.99** |
| Error | 28 | 141.16 | 5.04 | |

**Denotes significant differences at P = 0.01.

Table 6. Analysis of variance for root elongation data taken from corn roots treated with Triton X-102, an octyl phenol derivative, and Triton N-128, a nonyl phenol derivative, at each of 7 concentrations

| Source of variation | df | Sum of squares | Mean square | F values |
|---|---|---|---|---|
| Surfactant | 1 | 73.07 | 73.07 | 38.25** |
| Concentration | 6 | 1242.69 | 207.11 | 108.43** |
| Surfactant x Concentration | 6 | 63.64 | 10.61 | 5.55** |
| Error | 28 | 53.42 | 1.91 | |

**Denotes significant difference at P = 0.01.

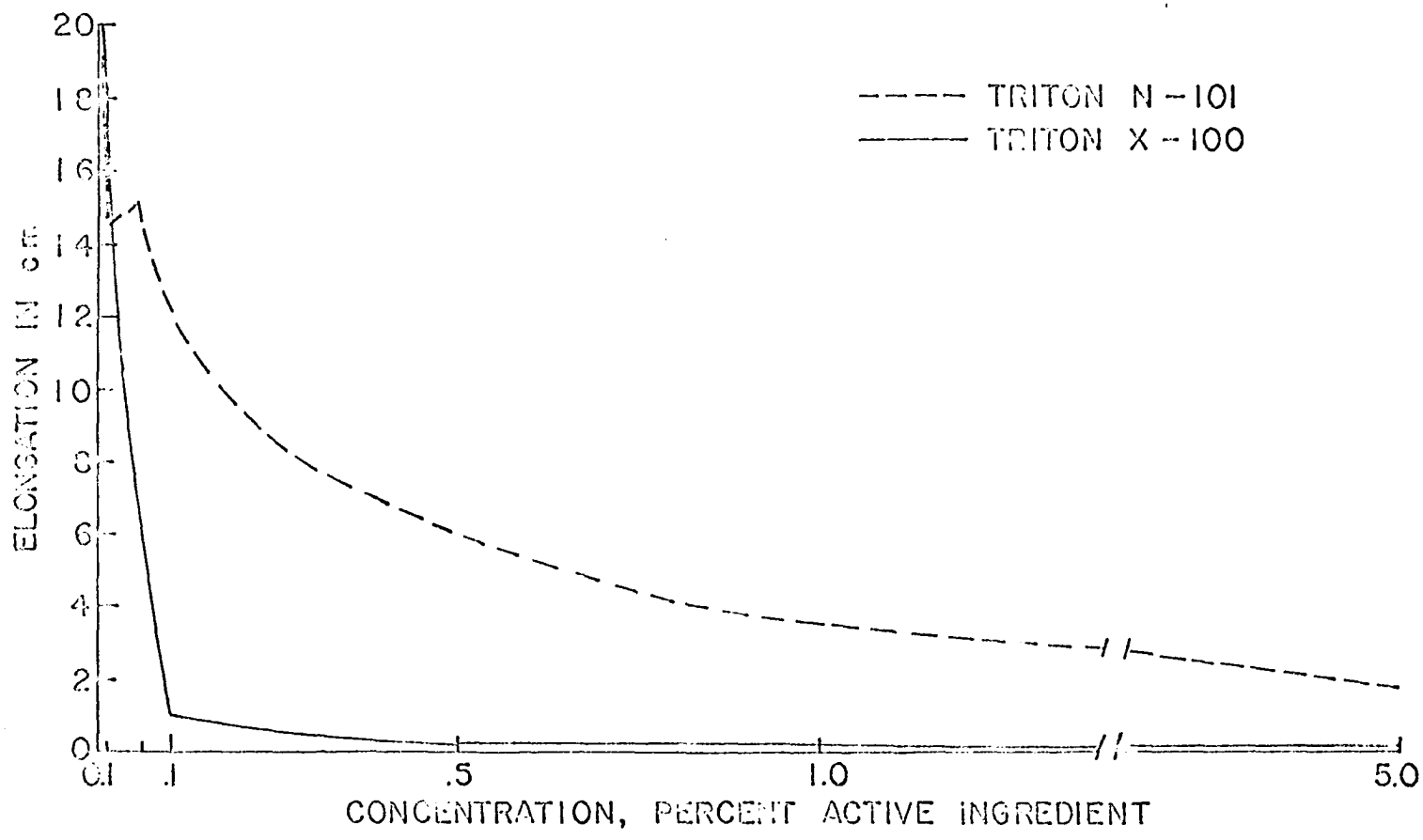



Figure 3. Elongation of corn roots, in centimeters, measured 3 days after treatment with 7 concentrations of selected surfactants from the Triton family; points are averages of measurements from 3 seedlings

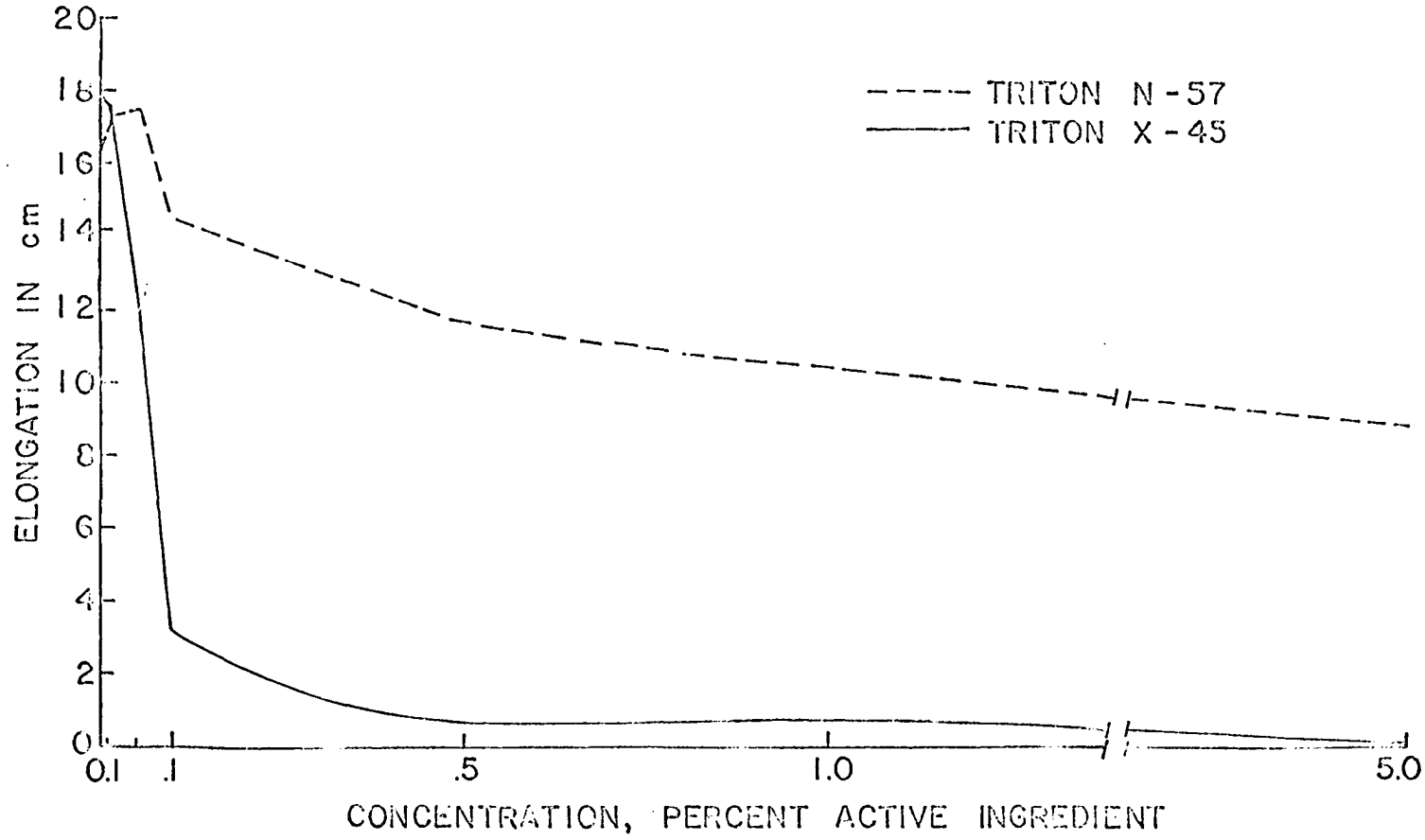



Figure 4. Elongation of corn roots, in centimeters, measured 3 days after treatment with 7 concentrations of selected surfactants from the Triton family; points are averages of measurements from 3 seedlings

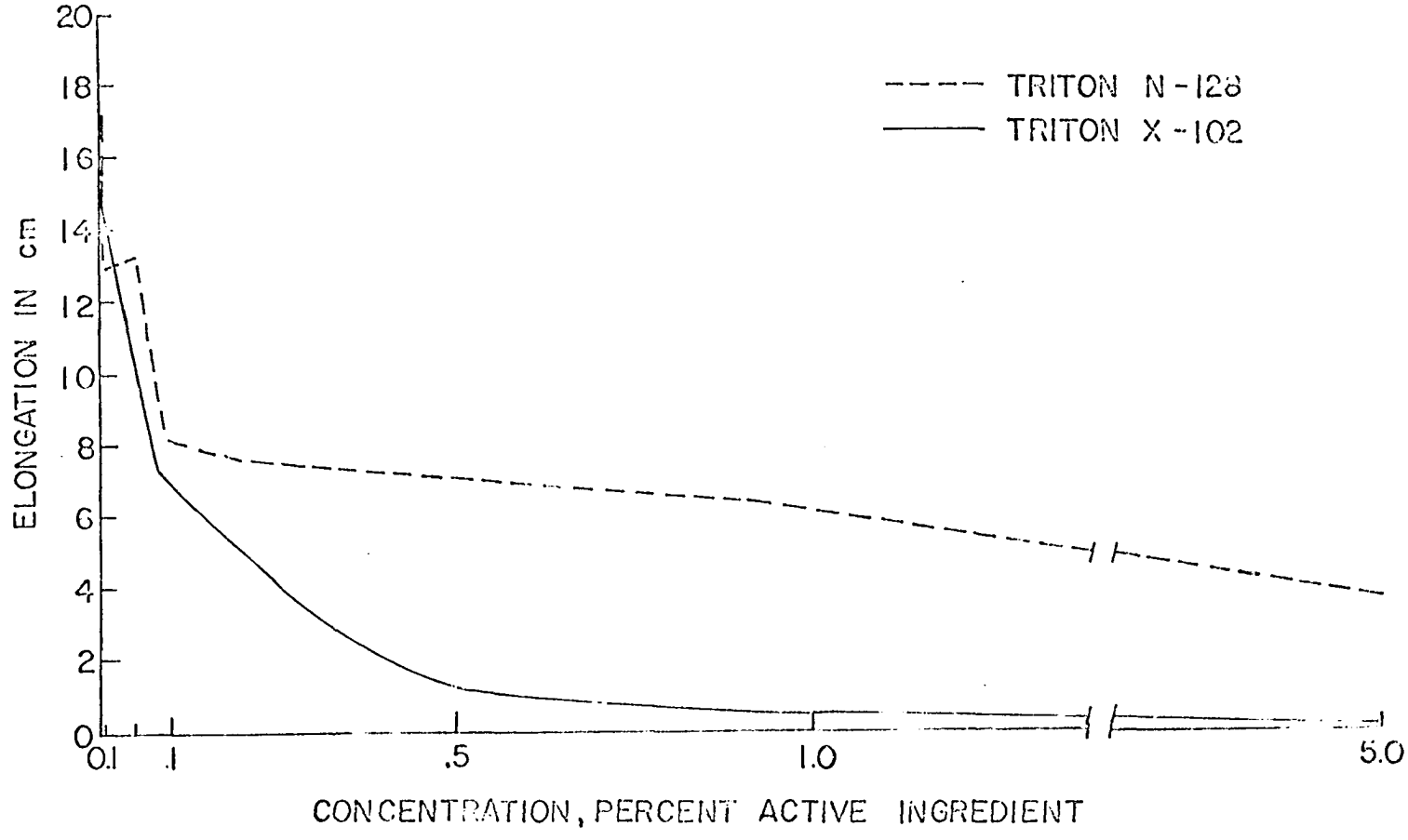



Figure 5. Elongation of corn roots, in centimeters, measured 3 days after treatment with 7 concentrations of selected surfactants from the Triton family; points are averages of measurements from 3 seedlings

Table 7. Leaf injury ratings, 2 days after treatment, for soybeans treated with 4 concentrations of various surfactants of the Triton family; ratings are based on a 0-5 scale; data are means of 3 observations

| Surfactant | Concentration 1.0 | .1 | .01 | Ck |
|---|---|---|---|---|
| Triton N-57 | 2 | 1 | 0 | 0 |
| Triton N-101 | 3 | 2 | 0 | 0 |
| Triton N-128 | 3 | 2 | 0 | 0 |
| Triton X-15 | 4 | 3 | 3 | 0 |
| Triton X-35 | 4 | 3 | 1 | 0 |
| Triton X-45 | 4 | 1 | 0 | 0 |
| Triton X-100 | 4 | 1 | 0 | 0 |
| Triton X-102 | 4 | 2 | 0 | 0 |
| Triton X-114 | 4 | 2 | 0 | 0 |
| Triton X-165 | 4 | 1 | 0 | 0 |
| Triton X-205 | 3 | 1 | 0 | 0 |
| Triton X-305 | 1 | 0 | 0 | 0 |

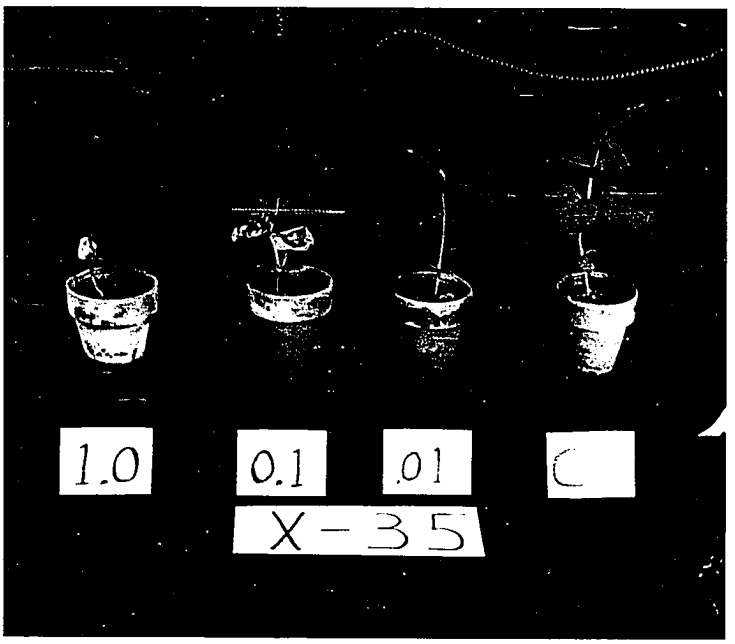
Table 8. Dry weight in grams of soybean plant parts, cut off above the cotyledons, 14 days after treatment with 4 concentrations of various surfactants from the Triton family; each datum represents an average of 3 replications

| Surfactant | Concentration 1.0 | .1 | .01 | Ck |
|---|---|---|---|---|
| Triton N-57 | .282 | .375 | .295 | .425 |
| Triton N-101 | .099 | .359 | .365 | .356 |
| Triton N-128 | .130 | .367 | .374 | .394 |
| Triton X-15 | .075 | .266 | .269 | .288 |
| Triton X-35 | .000 | .184 | .405 | .318 |
| Triton X-45 | .000 | .320 | .340 | .340 |
| Triton X-100 | .000 | .330 | .322 | .430 |
| Triton X-102 | .000 | .296 | .338 | .328 |
| Triton X-114 | .023 | .243 | .305 | .325 |
| Triton X-165 | .116 | .267 | .392 | .349 |
| Triton X-205 | .142 | .278 | .303 | .329 |
| Triton X-305 | .224 | .293 | .315 | .312 |

Figure 6. Soybean injury as reflected by development of the first trifoliate leaf; photo taken 5 days after treatment with 1.0 percent concentrations of Triton X-305, X-205, X-165, X-100, and X-45; the progressive increase in injury as illustrated, left to right, reflects the decrease in polyoxyethylene content of surfactants from Triton X-305 down to Triton X-45

Figure 7. Soybean injury as reflected by development of the first trifoliate leaf; photos taken 5 days after treatment with Triton surfactants: (a) X-35, (b) X-114, (c) X-165, and (d) X-305, at 4 concentrations; the progressive decrease in injury as illustrated, reflects the increase in polyoxyethylene content of surfactants from Triton X-45 to Triton X-305

(a)




(b)

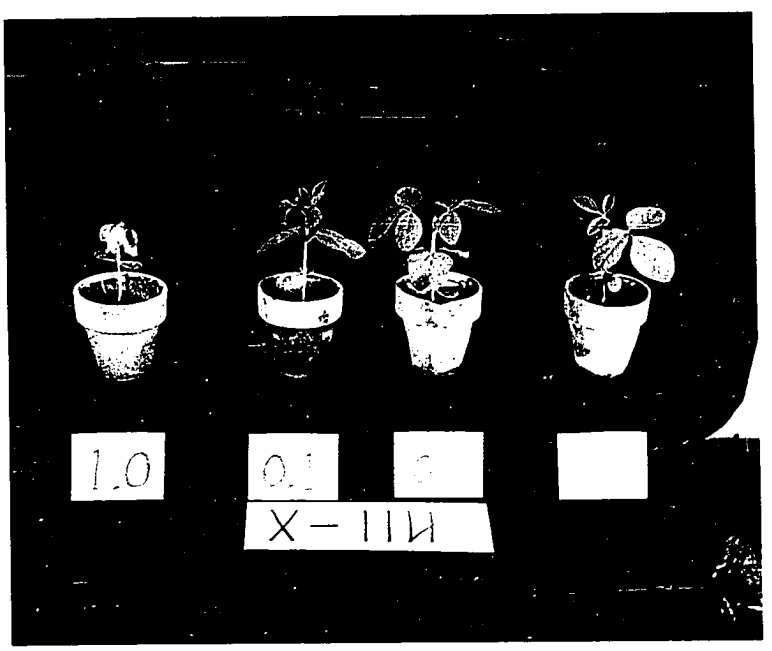
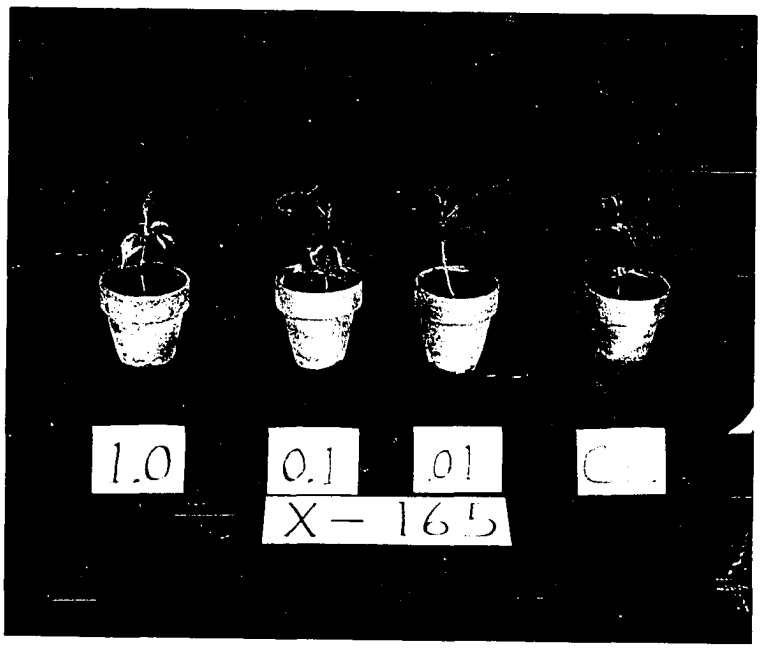


Figure 7. (Continued)

(c)




(d)

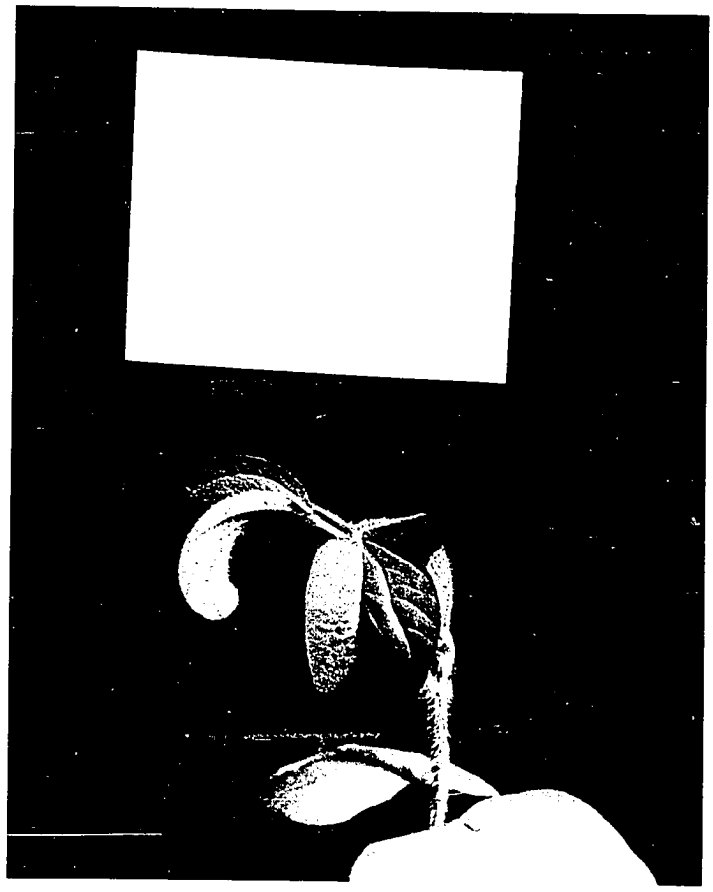


Figure 8. Typical injury of the first trifoliate leaf of young soybeans when treated with lower concentrations of surfactants; photo taken 5 days after treatment with a 0.01 percent concentration of Triton X-102

Tetronics

In general, the Tetronic surfactants were not inhibitory to germination. Tetronic 701, which contained the lowest percentage of the hydrophilic polyoxyethylene units per molecule, was the most active surfactant in the series. Only slight inhibition of germination was demonstrated by other members of this group. These observations are summarized in Table 9. The effects of these surfactants on the elongation of corn roots varied with the percent of polyoxyethylene present, as observed in Table 10. Tetronic 701 was the most inhibitory member of the series. Tetronic 704 and 707, which contained 40 to 49 percent and 70 to 79 percent polyoxyethylene respectively, showed a decrease in toxicity with an increase in polyoxyethylene content. Tetronic 908, which had a slightly longer hydrophobe and 80 to 89 percent polyoxyethylene, had only slight effect on root elongation. Evidence of greater toxicity was apparent at concentrations of 0.05 percent and higher. Tetronic 304 and 704, which contained comparable percentages of polyoxyethylene, but contained different length hydrophobes (501 to 1,000 and 2,501 to 3,000 molecular weight, respectively), differed little in toxicity. At concentrations of 0.5 percent and higher, Tetronic 304 was slightly more toxic than Tetronic 704.

Of the Tetronic surfactants tested, only Tetronic 701, at concentrations of 1.0 percent, gave any reduction in dry weight when applied as a foliar application. These data are summarized in Tables 11 and 12, and illustrated in Figure 9.

Table 9. Total number of seeds of corn, oats, radish, and giant foxtail germinating 7 days after treatment with 7 concentrations of selected surfactants from the Tetronic and Pluronic families; data are counts from 45 seeds, 3 replications of 15 seeds each for corn, oats, and radish; and 75 seeds, 3 replications of 25 seeds each for giant foxtail

| Surfactant | Concentration 5 | 1 | .5 | .1 | .05 | .01 | Ck | 5 | 1 | .5 | .1 | .05 | .01 | Ck |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Corn | | | | | | | Oats | | | | | | |
| Tetronic 304 | 20 | 42 | 44 | 45 | 45 | 45 | 43 | 29 | 38 | 42 | 34 | 37 | 39 | 41 |
| Tetronic 701 | 2 | 33 | 42 | 45 | 45 | 42 | 45 | 0 | 5 | 4 | 6 | 16 | 14 | 36 |
| Tetronic 704 | 30 | 45 | 44 | 45 | 45 | 44 | 44 | 9 | 9 | 15 | 19 | 18 | 25 | 37 |
| Tetronic 707 | 45 | 45 | 45 | 45 | 45 | 45 | 45 | 14 | 27 | 20 | 29 | 37 | 35 | 36 |
| Tetronic 908 | 44 | 45 | 45 | 44 | 44 | 44 | 45 | 29 | 20 | 29 | 24 | 28 | 32 | 39 |
| Pluronic F-38 | 43 | 44 | 45 | 45 | 44 | 45 | 45 | 43 | 37 | 38 | 41 | 41 | 40 | 44 |
| Pluronic F-68 | 44 | 45 | 45 | 45 | 45 | 45 | 44 | 28 | 26 | 26 | 23 | 39 | 31 | 41 |
| Pluronic F-88 | 44 | 40 | 45 | 45 | 45 | 45 | 45 | 21 | 23 | 22 | 32 | 34 | 36 | 38 |
| Pluronic F-98 | 45 | 45 | 45 | 45 | 44 | 45 | 45 | 25 | 32 | 29 | 38 | 34 | 38 | 42 |
| Pluronic F-108 | 45 | 45 | 44 | 45 | 45 | 44 | 44 | 21 | 16 | 19 | 18 | 19 | 26 | 39 |
| | Radish | | | | | | | Giant Foxtail | | | | | | |
| Tetronic 304 | 45 | 45 | 45 | 45 | 45 | 45 | 45 | 50 | 69 | 59 | 66 | 65 | 66 | 65 |
| Tetronic 701 | 0 | 45 | 45 | 42 | 45 | 45 | 45 | 0 | 23 | 51 | 62 | 61 | 60 | 69 |
| Tetronic 704 | 44 | 42 | 45 | 45 | 45 | 45 | 45 | 46 | 61 | 59 | 55 | 54 | 65 | 56 |
| Tetronic 707 | 45 | 45 | 45 | 44 | 45 | 44 | 43 | 60 | 57 | 62 | 61 | 62 | 59 | 62 |
| Tetronic 908 | 45 | 44 | 42 | 43 | 43 | 45 | 42 | 64 | 59 | 68 | 62 | 63 | 64 | 64 |
| Pluronic F-38 | 45 | 45 | 45 | 45 | 45 | 45 | 45 | 71 | 60 | 69 | 63 | 64 | 68 | 66 |
| Pluronic F-68 | 44 | 45 | 43 | 44 | 45 | 44 | 45 | 65 | 58 | 61 | 56 | 58 | 59 | 57 |
| Pluronic F-88 | 45 | 42 | 44 | 43 | 44 | 42 | 41 | 63 | 62 | 61 | 63 | 63 | 65 | 69 |
| Pluronic F-98 | 43 | 43 | 31 | 41 | 41 | 40 | 43 | 54 | 63 | 64 | 59 | 60 | 57 | 59 |
| Pluronic F-108 | 44 | 44 | 44 | 41 | 45 | 44 | 42 | 61 | 52 | 52 | 62 | 59 | 64 | 58 |

Table 10. Elongation of corn roots, in centimeters, measured 3 days after treatment with 7 concentrations of selected surfactants from the Tetronic and Pluronic families; data are averages of measurements from 3 seedlings

| Surfactant | Concentration 0.0 | .01 | .05 | .1 | .5 | 1.0 | 5.0 |
|---|---|---|---|---|---|---|---|
| Tetronic 304 | 17.4 | 15.5 | 16.9 | 12.7 | 9.7 | 8.0 | 5.1 |
| Tetronic 701 | 15.4 | 12.0 | 11.1 | 7.0 | 6.1 | 5.6 | 2.5 |
| Tetronic 704 | 16.2 | 14.5 | 16.9 | 12.0 | 12.0 | 14.0 | 5.5 |
| Tetronic 707 | 16.8 | 17.4 | 17.3 | 12.8 | 16.5 | 17.5 | 14.5 |
| Tetronic 908 | 16.8 | 17.3 | 14.9 | 15.1 | 16.0 | 15.7 | 12.9 |
| Pluronic F-38 | 16.1 | 16.6 | 20.2 | 18.7 | 16.6 | 16.7 | 16.6 |
| Pluronic F-68 | 17.3 | 18.4 | 14.4 | 17.9 | 17.4 | 19.0 | 16.6 |
| Pluronic F-88 | 18.5 | 19.8 | 20.1 | 17.6 | 19.8 | 18.9 | 16.3 |
| Pluronic F-98 | 15.9 | 16.8 | 16.9 | 16.4 | 18.8 | 19.2 | 14.3 |
| Pluronic F-108 | 14.8 | 15.2 | 16.7 | 13.5 | 14.7 | 15.7 | 16.1 |

Table 11. Leaf injury ratings, 2 days after treatment, for soybeans treated with 4 concentrations of various surfactants of the Tetronic and Pluronic families; ratings are based on a 0-5 scale; data are means of 3 observations

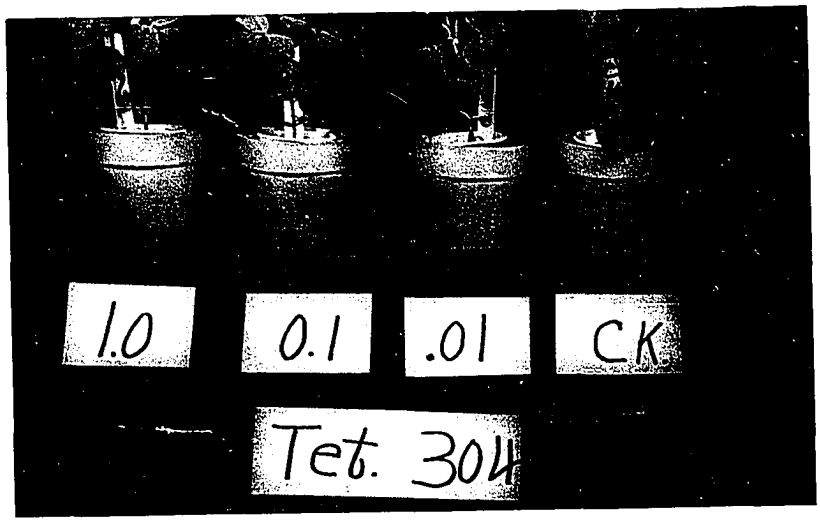
| Surfactant | Concentration 1.0 | .1 | .01 | Ck |
|---|---|---|---|---|
| Tetronic 304 | 0 | 0 | 0 | 0 |
| Tetronic 701 | 2 | 1 | 0 | 0 |
| Tetronic 704 | 0 | 0 | 0 | 0 |
| Tetronic 707 | 0 | 0 | 0 | 0 |
| Tetronic 908 | 0 | 0 | 0 | 0 |
| Pluronic F-38 | 0 | 0 | 0 | 0 |
| Pluronic F-68 | 0 | 0 | 0 | 0 |
| Pluronic F-88 | 0 | 0 | 0 | 0 |
| Pluronic F-98 | 0 | 0 | 0 | 0 |
| Pluronic F-108 | 0 | 0 | 0 | 0 |

Table 12. Dry weight in grams of soybean plant parts, cut off above the cotyledons, 14 days after treatment with 4 concentrations of various surfactants from the Tetronic and Pluronic families; each datum represents an average of 3 replications

| Surfactant | Concentration 1.0 | .1 | .01 | Ck |
|---|---|---|---|---|
| Tetronic 304 | .428 | .450 | .439 | .369 |
| Tetronic 701 | .165 | .265 | .300 | .372 |
| Tetronic 704 | .345 | .427 | .448 | .424 |
| Tetronic 707 | .367 | .345 | .286 | .405 |
| Tetronic 908 | .466 | .379 | .309 | .319 |
| Pluronic F-38 | .332 | .381 | .315 | .374 |
| Pluronic F-68 | .375 | .440 | .408 | .456 |
| Pluronic F-88 | .356 | .394 | .363 | .393 |
| Pluronic F-98 | .322 | .383 | .423 | .364 |
| Pluronic F-108 | .386 | .452 | .469 | .406 |

Figure 9. Soybean injury as reflected by development of the first trifoliate leaf; photos taken 5 days after treatment with Tetronic surfactants: (a) 304, (b) 701, and (c) 908, at 4 concentrations; variations in injury as illustrated reflect a variation in either hydrophobic or hydrophilic properties of the surfactant

(a)




(b)

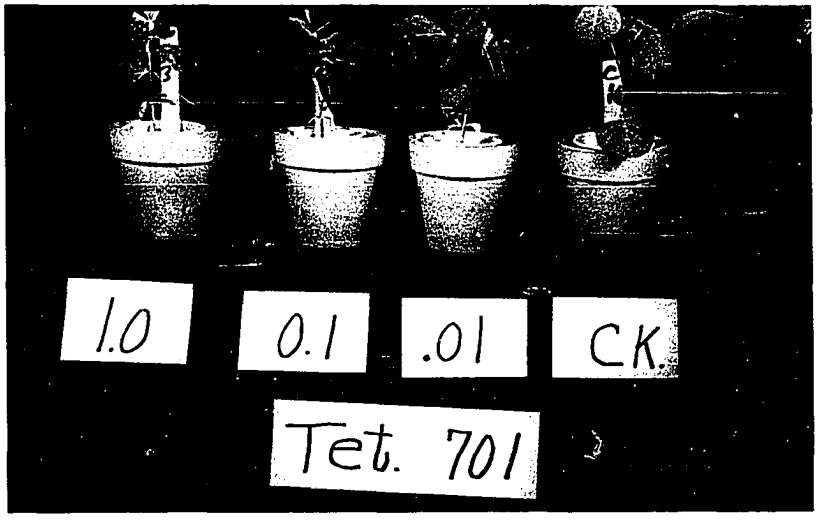
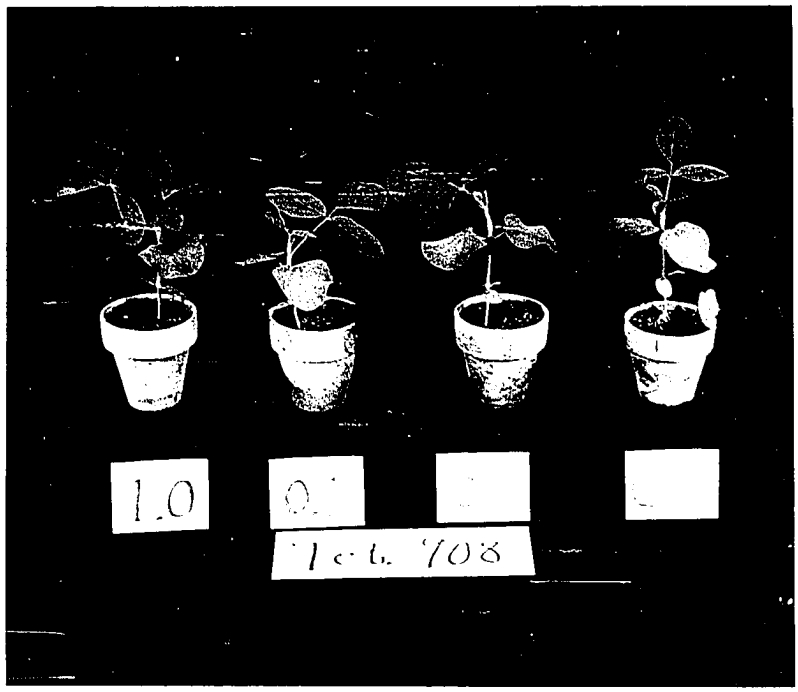


Figure 9. (Continued)

(c)



Pluronics

One group of Pluronics comprises a series of surfactants in which approximately 80 percent of the molecule, by weight, consists of hydrophilic polyoxyethylene groups; the remaining 20 percent of the molecule is hydrophobic polyoxypropylene, which varies from a molecular weight of 3,250 in Pluronic F-108 to 950 in Pluronic F-38. These surfactants did not suppress germination of either corn, oats, radish or giant foxtail. These results are presented in Table 9. Similarly, there was no inhibition of elongation of corn roots at any of the concentrations tested, as shown in Table 10. Members of this series of surfactants applied to soybeans as a foliar application at concentrations up to 1.0 percent demonstrated no signs of toxicity. Data from these experiments are summarized in Tables 11 and 12.

Igepal

Within the Igepal Co- series of surfactants members containing 20 moles or less of polyoxyethylene per mole of nonyl phenol displayed a greater degree of toxicity to seed germination than did members containing greater amounts of polyoxyethylene. These data are presented in Table 13. Igepal Co-630 and Co-730 were the most toxic, especially on oats, higher members of the series displayed a decreasing toxicity. The responses of corn roots to these surfactants paralleled closely the responses of germinating seeds. Table 14 shows the inhibition of root elongation when seedlings were treated with Co-630, Co-730, and Co-850, which contained 9 to 10, 15, and 20 moles of polyoxyethylene per mole of nonyl phenol, respectively, at concentrations of 0.05 percent or more.

Table 13. Total number of seeds of corn, oats, radish, and giant foxtail germinating 7 days after treatment with 7 concentrations of selected surfactants from the Igepal and Deriphat families; data are counts from 45 seeds, 3 replications of 15 seeds each for corn, oats, and radish; and 75 seeds, 3 replications of 25 seeds each for giant foxtail

| Surfactant | Concentration | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 5 | 1 | .5 | .1 | .05 | .01 | Ck | 5 | 1 | .5 | .1 | .05 | .01 | Ck |
| | Corn | | | | | | | Oats | | | | | | |
| Igepal Co-630 | 38 | 30 | 24 | 37 | 43 | 45 | 45 | 0 | 2 | 0 | 3 | 6 | 23 | 40 |
| Igepal Co-730 | 26 | 29 | 27 | 22 | 33 | 44 | 45 | 1 | 0 | 2 | 10 | 12 | 31 | 42 |
| Igepal Co-850 | 36 | 37 | 36 | 43 | 44 | 45 | 45 | 7 | 11 | 6 | 12 | 13 | 19 | 35 |
| Igepal Co-890 | 40 | 40 | 38 | 39 | 45 | 45 | 45 | 27 | 17 | 21 | 24 | 20 | 31 | 40 |
| Igepal Co-970 | 44 | 44 | 45 | 45 | 44 | 45 | 45 | 30 | 25 | 20 | 33 | 34 | 38 | 40 |
| Igepal Co-990 | 45 | 44 | 44 | 45 | 43 | 45 | 45 | 41 | 27 | 19 | 31 | 26 | 37 | 36 |
| Deriphat 151 | 4 | 1 | 5 | 38 | 40 | 45 | 45 | 0 | 0 | 0 | 1 | 6 | 19 | 38 |
| Deriphat 154 | 0 | 32 | 42 | 44 | 45 | 45 | 45 | 0 | 0 | 0 | 12 | 13 | 23 | 38 |
| Deriphat 160 | 0 | 16 | 27 | 43 | 43 | 45 | 45 | 0 | 0 | 1 | 9 | 27 | 37 | 43 |
| | Radish | | | | | | | Giant Foxtail | | | | | | |
| Igepal Co-630 | 26 | 29 | 43 | 43 | 45 | 45 | 45 | 26 | 54 | 58 | 57 | 60 | 54 | 63 |
| Igepal Co-730 | 45 | 43 | 44 | 44 | 45 | 45 | 44 | 42 | 40 | 51 | 56 | 54 | 58 | 61 |
| Igepal Co-850 | 44 | 44 | 45 | 45 | 45 | 45 | 45 | 42 | 51 | 57 | 53 | 58 | 66 | 61 |
| Igepal Co-890 | 44 | 44 | 45 | 44 | 44 | 45 | 44 | 48 | 63 | 54 | 62 | 52 | 65 | 66 |
| Igepal Co-970 | 44 | 45 | 44 | 45 | 44 | 44 | 45 | 40 | 56 | 59 | 55 | 58 | 56 | 48 |
| Igepal Co-990 | 43 | 44 | 45 | 43 | 45 | 45 | 45 | 49 | 55 | 54 | 64 | 60 | 58 | 63 |
| Deriphat 151 | 0 | 0 | 0 | 39 | 44 | 45 | 45 | 0 | 0 | 1 | 45 | 61 | 58 | 64 |
| Deriphat 154 | 0 | 9 | 20 | 43 | 45 | 45 | 45 | 0 | 14 | 48 | 57 | 56 | 61 | 63 |
| Deriphat 160 | 0 | 0 | 0 | 45 | 45 | 45 | 45 | 0 | 0 | 20 | 54 | 62 | 68 | 70 |

Table 14. Elongation of corn roots, in centimeters, measured 3 days after treatment with 7 concentrations of selected surfactants from the Igepal and Deriphat families; data are averages of measurements from 3 seedlings

| Surfactant | Concentration 0.0 | .01 | .05 | 0.1 | 0.5 | 1.0 | 5.0 |
|---|---|---|---|---|---|---|---|
| Igepal Co-630 | 16.8 | 16.7 | 9.3 | 9.1 | 3.3 | 4.5 | 3.2 |
| Igepal Co-730 | 18.4 | 13.0 | 12.2 | 9.1 | 9.1 | 8.3 | 6.9 |
| Igepal Co-850 | 18.1 | 12.8 | 11.3 | 10.0 | 9.4 | 9.2 | 8.4 |
| Igepal Co-890 | 16.7 | 15.5 | 17.8 | 15.2 | 16.3 | 18.8 | 15.8 |
| Igepal Co-970 | 17.6 | 15.7 | 16.7 | 14.3 | 16.7 | 15.0 | 16.4 |
| Igepal Co-990 | 18.1 | 17.4 | 16.4 | 15.4 | 15.7 | 15.9 | 16.2 |
| Deriphat 151 | 18.8 | 10.1 | 4.0 | 1.9 | 1.1 | 0.5 | 0.1 |
| Deriphat 154 | 19.6 | 12.4 | 11.4 | 7.7 | 4.2 | 1.7 | 0.0 |
| Deriphat 160 | 17.6 | 19.3 | 13.7 | 9.2 | 4.6 | 1.5 | 0.1 |
| Deriphat 151C | 14.3 | 14.4 | 4.8 | 2.5 | 3.2 | 0.4 | 0.2 |
| Deriphat 160C | 16.1 | 15.4 | 12.0 | 8.2 | 1.6 | 0.4 | 0.0 |
| Deriphat 170C | 15.8 | 9.3 | 2.5 | 1.9 | 0.3 | 0.0 | 0.0 |

Members of the series containing 30 moles of polyoxyethylene or more, per mole of nonyl phenol (Co-890, Co-970, or Co-990), had no effect on elongation of corn roots. Foliar applications of the Igepal surfactants demonstrated an increase in toxicity with a decrease in percentage of polyoxyethylene present, as shown in Tables 15 and 16, and Figures 10, 11, and 12. Reduction of leaf dry matter yield was substantial with the 1.0 percent concentration, but only slight reductions were evident with any of the 0.1 percent concentrations.

Deriphats

Deriphats are amphoteric surfactants containing both carboxyl and amino functionality in their structure. They were inhibitory to seed germination. These observations are summarized in Table 13. Deriphat 151 (sodium N-coco$\beta$-aminopropionate) was slightly more inhibitory than either Deriphat 154 (di-sodium N-tallow$\beta$-aminodipropionate) or Deriphat 160 (di-sodium N-lauryl$\beta$-iminodipropionate). Oats were most sensitive, radish and giant foxtail intermediate in reaction, and corn least sensitive. Elongation of corn roots was inhibited severely by all members of this group as shown in Table 14. Almost 50 percent reduction in length of roots occurred with 0.01, 0.05, and 0.1 percent concentrations of Deriphats 151, 154, and 160, respectively. Deriphat 151C (coco- derivative of$\beta$-aminopropionic acid) and Deriphat 170C (lauryl, myristyl derivative of$\beta$-aminopropionic acid) were effective inhibitors of the growth of corn roots at concentrations of 0.05 percent or more. Deriphat 160C (a partial sodium salt of lauryl$\beta$-iminodipropionic acid), gave substantial reductions in elongation of corn roots only at concentrations greater than 0.1 percent.

Table 15. Leaf injury ratings, 2 days after treatment, for soybeans treated with 4 concentrations of various surfactants of the Igepal and Deriphat families; ratings are based on a 0-5 scale; data are means of 3 observations

| Surfactant | Concentration 1.0 | .1 | .01 | Ck |
|---|---|---|---|---|
| Igepal Co-990 | 0 | 0 | 0 | 0 |
| Igepal Co-970 | 0 | 0 | 0 | 0 |
| Igepal Co-890 | 0 | 0 | 0 | 0 |
| Igepal Co-850 | 3 | 2 | 0 | 0 |
| Igepal Co-630 | 3 | 2 | 1 | 0 |
| Igepal Co-730 | 3 | 2 | 0 | 0 |
| Deriphat 151 | 3 | 1 | 0 | 0 |
| Deriphat 151C | 4 | 1 | 0 | 0 |
| Deriphat 170C | 4 | 1 | 0 | 0 |
| Deriphat 160 | 1 | 0 | 0 | 0 |
| Deriphat 160C | 2 | 0 | 0 | 0 |
| Deriphat 154 | 0 | 0 | 0 | 0 |

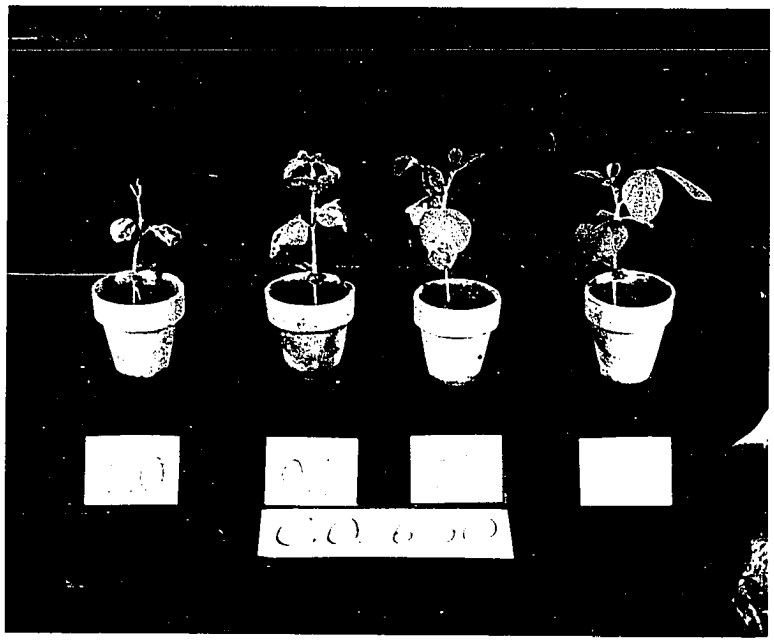
Table 16. Dry weight in grams of soybean plant parts, cut off above the cotyledons, 14 days after treatment with 4 concentrations of various surfactants from the Igepal and Deriphat families; each datum represents an average of 3 replications

| Surfactant | Concentration 1.0 | .1 | .01 | Ck |
|---|---|---|---|---|
| Igepal Co-990 | .266 | .365 | .302 | .331 |
| Igepal Co-970 | .297 | .359 | .394 | .358 |
| Igepal Co-890 | .350 | .301 | .377 | .337 |
| Igepal Co-850 | .195 | .310 | .384 | .323 |
| Igepal Co-630 | .139 | .239 | .437 | .308 |
| Igepal Co-730 | .123 | .245 | .313 | .306 |
| Deriphat 151 | .014 | .272 | .345 | .355 |
| Deriphat 151C | .060 | .333 | .395 | .327 |
| Deriphat 170C | .009 | .285 | .369 | .305 |
| Deriphat 160 | .351 | .429 | .364 | .400 |
| Deriphat 160C | .328 | .385 | .380 | .357 |
| Deriphat 154 | .371 | .424 | .451 | .382 |

Figure 10. Soybean injury as reflected by development of the first trifoliate leaf; photo taken 5 days after treatment with 1.0 percent concentration of Igepal Co-630, Co-730, Co-850, Co-870, and Co-970; the progressive decrease in injury as illustrated, left to right, reflects an increase in polyoxyethylene content of surfactants from Igepal Co-630 to Igepal Co-970

Figure 11. Soybean injury as reflected by development of the first trifoliate leaf; photos taken 5 days after treatment with (a) Igepal Co-630, (b) Igepal Co-730, and (c) Igepal Co-890 at 4 concentrations; the progressive decrease in injury as illustrated, top to bottom, reflects the increase in polyoxyethylene content of the Igepal Co- series of surfactants

(a)



(b)

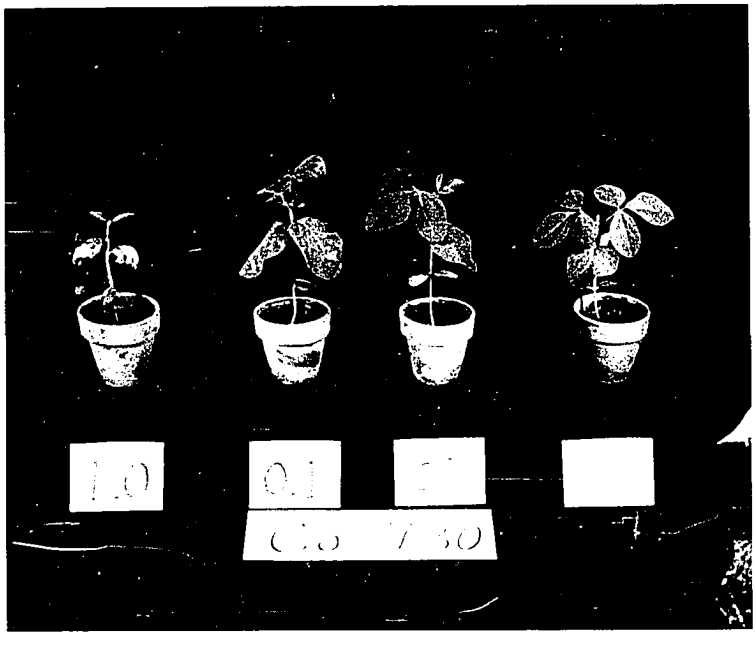


Figure 11. (Continued)

(c)

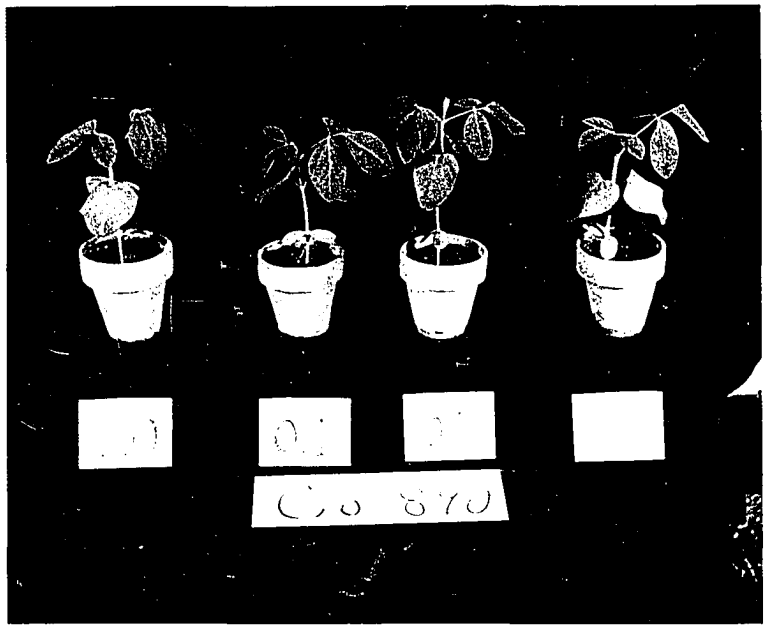
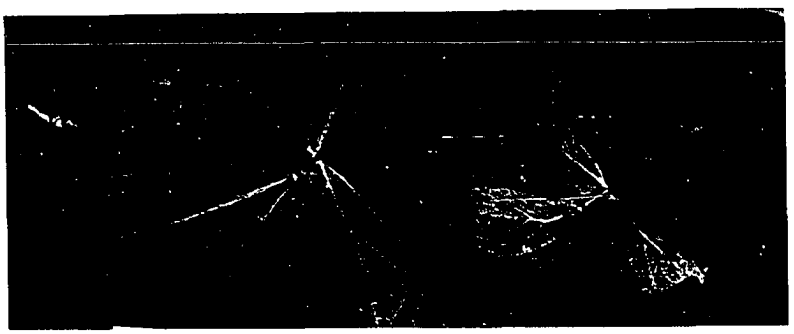
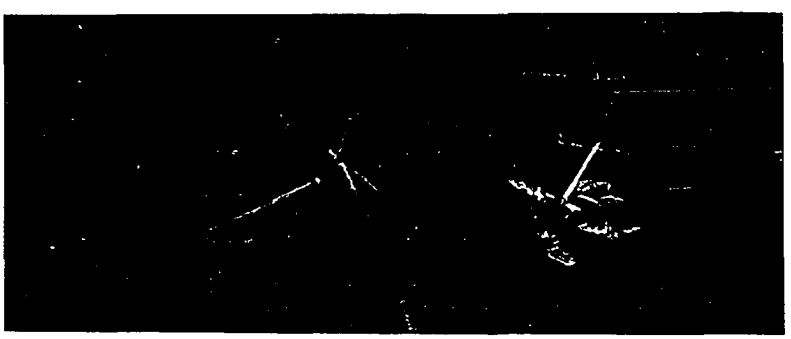


Figure 12. Typical injury of either the first trifoliate or unifoliate leaf of young soybeans when treated with lower concentrations of surfactants; photos taken 5 days after treatment with (a) 0.01 percent, (b) 0.1 percent, and (c) 1.0 percent concentration of Igepal Co-630; non-treated leaves are on the left

(a)



(b)



(c)

Foliar applications of these surfactants resulted in various levels of growth inhibition. Deriphat 151 prevented growth almost completely at 1.0 percent, whereas Deriphats 154 and 160 had no appreciable effect on growth when applied as a foliar application. These effects are presented in Tables 15 and 16, and illustrated in Figure 13. Of the acid forms, Deriphats 151C and 170C gave almost complete inhibition of growth at 1.0 percent concentration. Plants treated with Deriphat 160C produced a normal amount of dry matter. Concentrations of less than 1.0 percent produced only slight reductions in growth of the first trifoliate leaf, as measured by dry matter yield.

Emulsynts

The Emulsynts, a series of surfactants comprised of glycol laurate with increasing amounts of polyoxyethylene, inhibited germination only at very high concentrations, as shown in Table 17. Oats were the most sensitive with other species tested demonstrating a lesser degree of sensitivity.

Elongation of corn roots followed closely the response pattern observed for germination. These observations are summarized in Table 18. Appreciable inhibition occurred only at higher concentrations. Decreasing inhibition with increasing polyoxyethylene content was not as pronounced as that observed with families of surfactants discussed previously.

Foliar applications of the Emulsynts gave no clear-cut patterns of toxicity in relation to chemical structure of the surfactants as may be observed in Tables 19 and 20. Emulsynt 225, which contained more polyoxyethylene than either Emulsynt 219 or Emulsynt 224, was the most toxic; Emulsynt 224 and 610A inhibited growth of soybeans slightly when treated at 1.0 percent.

Figure 13. Soybean injury as reflected by development of the first trifoliate leaf; photos taken 5 days after treatment with (a) Deriphat 151, (b) Deriphat 154, and (c) Deriphat 160 at 4 concentrations; the difference in plant injury reflects a variation in chemical composition of the surfactants

(a)


(b)

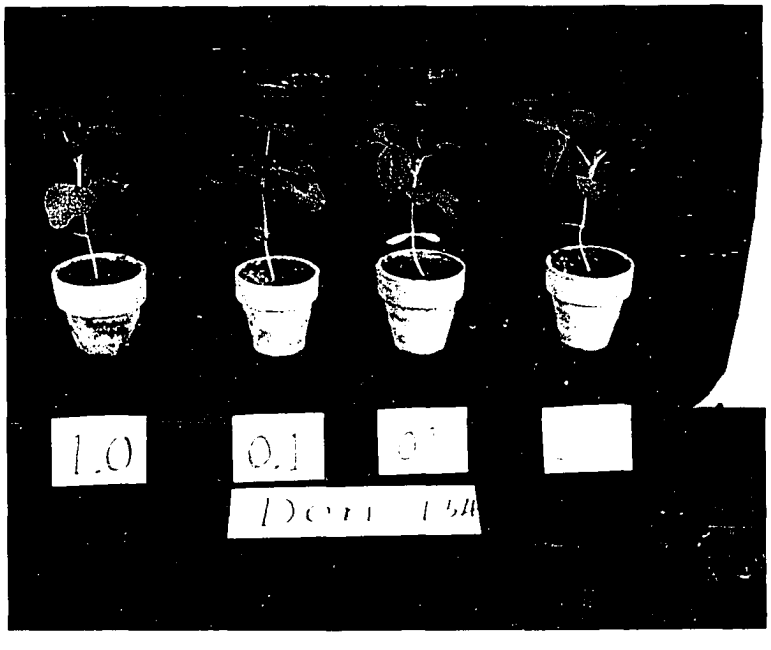


Figure 13. (Continued)

(c)

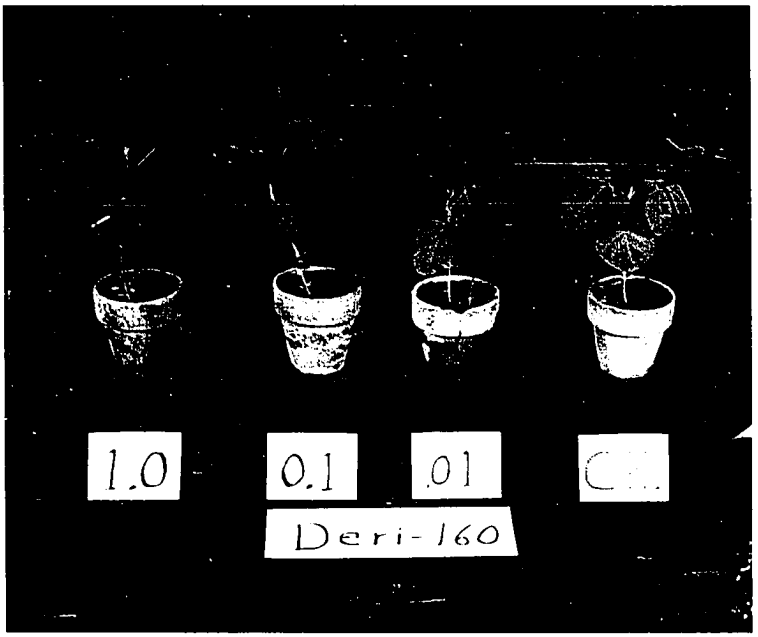


Table 17. Total number of seeds of corn, oats, radish, and giant foxtail germinating 7 days after treatment with 7 concentrations of selected surfactants from the Emulsynt and Tween families; data are counts from 45 seeds, 3 replications of 15 seeds each for corn, oats, and radish; and 75 seeds, 3 replications of 25 seeds each for giant foxtail

| Surfactant | Concentration | | | | | | | Concentration | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 5 | 1 | .5 | .1 | .05 | .01 | Ck | 5 | 1 | .5 | .1 | .05 | .01 | Ck |
| | Corn | | | | | | | Oats | | | | | | |
| Emulsynt 219 | 21 | 23 | 35 | 39 | 45 | 45 | 45 | 0 | 0 | 1 | 17 | 26 | 33 | 35 |
| Emulsynt 224 | 29 | 45 | 34 | 44 | 42 | 45 | 45 | 0 | 1 | 0 | 19 | 21 | 26 | 24 |
| Emulsynt 225 | 8 | 44 | 43 | 44 | 43 | 45 | 45 | 0 | 1 | 1 | 19 | 16 | 31 | 38 |
| Emulsynt 610A | 17 | 24 | 37 | 45 | 45 | 45 | 44 | 0 | 3 | 4 | 19 | 24 | 30 | 35 |
| Tween 20 | 29 | 27 | 26 | 42 | 44 | 45 | 45 | 0 | 4 | 8 | 17 | 15 | 26 | 42 |
| Tween 40 | 32 | 38 | 44 | 44 | 44 | 45 | 45 | 1 | 3 | 1 | 21 | 14 | 28 | 37 |
| Tween 60 | 31 | 39 | 43 | 45 | 45 | 44 | 45 | 14 | 17 | 12 | 18 | 26 | 42 | 41 |
| Tween 80 | 35 | 32 | 34 | 42 | 44 | 45 | 45 | 5 | 5 | 2 | 18 | 21 | 36 | 39 |
| Tween 85 | 40 | 37 | 44 | 44 | 43 | 45 | 45 | 13 | 13 | 15 | 22 | 24 | 30 | 41 |
| | Radish | | | | | | | Giant Foxtail | | | | | | |
| Emulsynt 219 | 21 | 41 | 44 | 44 | 41 | 44 | 44 | 3 | 45 | 54 | 54 | 60 | 58 | 58 |
| Emulsynt 224 | 17 | 30 | 38 | 35 | 42 | 44 | 44 | 1 | 32 | 50 | 45 | 57 | 57 | 60 |
| Emulsynt 225 | 12 | 41 | 42 | 43 | 42 | 45 | 44 | 5 | 29 | 46 | 54 | 55 | 61 | 51 |
| Emulsynt 610A | 38 | 40 | 46 | 43 | 44 | 44 | 42 | 3 | 40 | 49 | 62 | 51 | 55 | 42 |
| Tween 20 | 32 | 37 | 39 | 44 | 43 | 44 | 44 | 1 | 50 | 58 | 62 | 60 | 65 | 65 |
| Tween 40 | 45 | 44 | 45 | 45 | 42 | 45 | 45 | 57 | 65 | 68 | 63 | 65 | 65 | 68 |
| Tween 60 | 38 | 40 | 41 | 43 | 45 | 44 | 38 | 50 | 59 | 56 | 64 | 61 | 58 | 62 |
| Tween 80 | 40 | 43 | 36 | 45 | 44 | 43 | 45 | 51 | 54 | 55 | 53 | 51 | 62 | 66 |
| Tween 85 | 43 | 43 | 44 | 44 | 41 | 42 | 43 | 56 | 63 | 68 | 57 | 67 | 66 | 66 |

Table 18. Elongation of corn roots, in centimeters, measured 3 days after treatment with 7 concentrations of selected surfactants from the Emulsynt and Tween families; data are averages of measurements from 3 seedlings

| Surfactant | Concentration 0.0 | .01 | .05 | .1 | .5 | 1.0 | 5.0 |
|---|---|---|---|---|---|---|---|
| Emulsynt 219 | 15.2 | 18.7 | 17.4 | 17.0 | 10.1 | 8.0 | 2.3 |
| Emulsynt 224 | 16.3 | 17.5 | 17.5 | 17.4 | 10.7 | 4.9 | 4.4 |
| Emulsynt 225 | 17.3 | 15.3 | 12.4 | 13.4 | 12.1 | 10.3 | 6.2 |
| Emulsynt 610A | 16.9 | 18.3 | 18.0 | 18.0 | 14.3 | 13.4 | 10.0 |
| Tween 20 | 15.3 | 18.1 | 17.3 | 16.7 | 15.1 | 13.0 | 10.3 |
| Tween 40 | 15.6 | 15.7 | 14.7 | 20.4 | 17.4 | 17.7 | 15.2 |
| Tween 60 | 18.0 | 16.0 | 18.4 | 15.9 | 16.0 | 15.2 | 15.3 |
| Tween 80 | 15.6 | 18.4 | 18.0 | 17.1 | 16.6 | 16.7 | 14.4 |
| Tween 85 | 17.0 | 15.7 | 18.0 | 18.5 | 16.1 | 17.6 | 16.7 |

Table 19. Leaf injury ratings, 2 days after treatment, for soybeans treated with 4 concentrations of various surfactants of the Emulsynt and Tween families; ratings are based on a 0-5 scale; data are means of 3 observations

| Surfactant | Concentration 1.0 | .1 | .01 | Ck |
|---|---|---|---|---|
| Emulsynt 610A | 2 | 0 | 0 | 0 |
| Emulsynt 224 | 2 | 0 | 0 | 0 |
| Emulsynt 219 | 2 | 0 | 0 | 0 |
| Emulsynt 225 | 4 | 0 | 0 | 0 |
| Tween 20 | 2 | 0 | 0 | 0 |
| Tween 40 | 1 | 0 | 0 | 0 |
| Tween 60 | 0 | 0 | 0 | 0 |
| Tween 80 | 1 | 0 | 0 | 0 |
| Tween 85 | 1 | 0 | 0 | 0 |

Table 20. Dry weight in grams of soybean plant parts, cut off above the cotyledons, 14 days after treatment with 4 concentrations of various surfactants from the Emulsynt and Tween families; each datum represents an average of 3 replications

| Surfactant | Concentration 1.0 | .1 | .01 | Ck |
|---|---|---|---|---|
| Emulsynt 610A | .179 | .290 | .229 | .213 |
| Emulsynt 224 | .166 | .281 | .175 | .282 |
| Emulsynt 219 | .116 | .191 | .236 | .270 |
| Emulsynt 225 | .000 | .218 | .195 | .276 |
| Tween 20 | .273 | .416 | .356 | .370 |
| Tween 40 | .386 | .388 | .355 | .392 |
| Tween 60 | .390 | .332 | .371 | .366 |
| Tween 80 | .383 | .389 | .418 | .431 |
| Tween 85 | .352 | .528 | .376 | .370 |

Tweens

Members of the Tween series of surfactants, including Tweens 20, 40, 60, 80, and 85, which represent HLB (Hydrophile-Lipophile Balance) ratios of 11.0 to 16.7, were not toxic to seed germination in most cases. These data are presented in Table 17. Tweens 20, 40, and 80 were inhibitory to oats only at higher concentrations; Tweens 60 and 85 were less toxic. In general, Tween surfactants had no appreciable effect on elongation of corn roots at concentrations up to 5.0 percent as shown in Table 18. Tween 20, the most hydrophilic member of the series, inhibited growth to a very slight degree only at the highest concentrations. Except for a slight reduction in growth caused by a 1.0 percent treatment of Tween 20, the Tweens were not toxic when applied as foliar treatments. These effects are illustrated in Figure 14, and summarized in Tables 19 and 20.

Ultrawets

The Ultrawets, which are alkyl aryl sulfonates of the anionic type, were extremely potent germination inhibitors. These observations are summarized in Table 21. Little difference in the degree of inhibition was observed among various members of the family. The effects of these surfactants on root elongation are summarized in Table 22. Appreciable reductions in growth occurred with concentrations as low as 0.05 percent; at concentrations of 0.1 percent or greater, there was little growth after exposures of 3 days. Ultrawet DS and Ultrawet 30-DS (liquid form of DS), which are considered of medium molecular weight, were not as toxic at 0.05 percent as were Ultrawet K and Ultrawet SK, which are considered to have higher molecular weights. At concentrations other than 0.05 percent, responses were essentially equal.

Figure 14. Soybean injury as reflected by development of the first trifoliate leaf; photos taken 5 days after treatment with (a) Tween 20 and (b) Tween 80 at 4 concentrations; slight differences in injury reflects a variation in hydrophobic-hydrophilic ratio

(a)


(b)

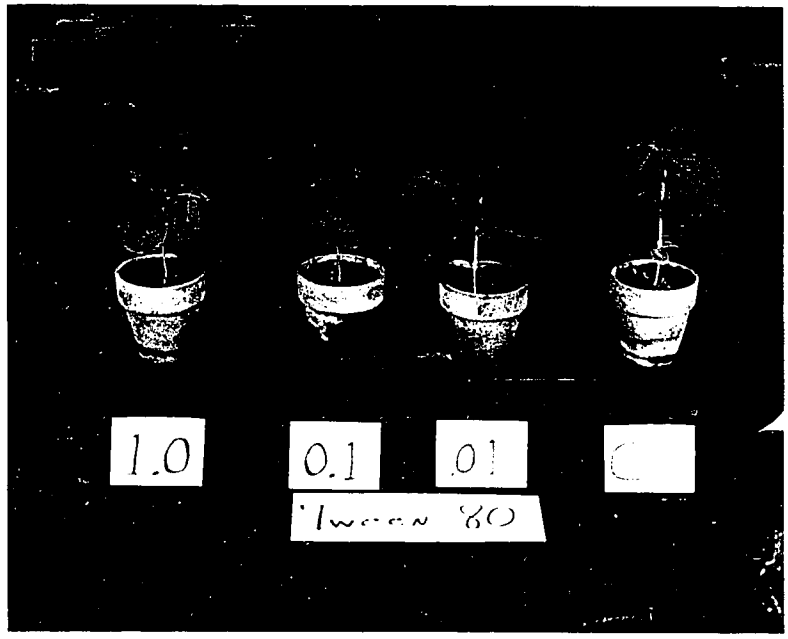


Table 21. Total number of seeds of corn, oats, radish, and giant foxtail germinating 7 days after treatment with 7 concentrations of selected surfactants from the Ultrawet and Miranol families; data are counts from 45 seeds, 3 replications of 15 seeds each for corn, oats, and radish; and 75 seeds, 3 replications of 25 seeds each for giant foxtail

| Surfactant | Concentration | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 5 | 1 | .5 | .1 | .05 | .01 | Ck | 5 | 1 | .5 | .1 | .05 | .01 | Ck |
| | Corn | | | | | | | Oats | | | | | | |
| Ultrawet DS | 0 | 0 | 0 | 38 | 45 | 44 | 45 | 0 | 0 | 0 | 0 | 3 | 21 | 37 |
| Ultrawet 30-DS | 0 | 0 | 0 | 21 | 43 | 45 | 45 | 0 | 0 | 0 | 0 | 0 | 18 | 38 |
| Ultrawet K | 0 | 0 | 0 | 44 | 45 | 45 | 44 | 0 | 0 | 0 | 0 | 1 | 23 | 37 |
| Ultrawet SK | 0 | 0 | 4 | 45 | 44 | 45 | 44 | 0 | 0 | 0 | 0 | 2 | 36 | 40 |
| Miranol CM | 0 | 36 | 43 | 45 | 45 | 45 | 45 | 0 | 0 | 0 | 3 | 1 | 17 | 30 |
| Miranol HM | 0 | 19 | 29 | 40 | 45 | 45 | 45 | 0 | 0 | 0 | 0 | 2 | 15 | 39 |
| Miranol DM | | | 45 | 44 | 45 | 45 | 45 | | | 31 | 24 | 44 | 42 | 39 |
| | Radish | | | | | | | Giant Foxtail | | | | | | |
| Ultrawet DS | 0 | 0 | 0 | 37 | 45 | 43 | 42 | 0 | 0 | 0 | 17 | 47 | 51 | 66 |
| Ultrawet 30-DS | 0 | 0 | 0 | 27 | 45 | 42 | 42 | 0 | 0 | 0 | 4 | 48 | 64 | 64 |
| Ultrawet K | 0 | 0 | 0 | 7 | 44 | 45 | 40 | 0 | 0 | 0 | 17 | 45 | 61 | 62 |
| Ultrawet SK | 0 | 0 | 0 | 42 | 43 | 44 | 44 | 0 | 0 | 0 | 36 | 48 | 67 | 67 |
| Miranol CM | 0 | 0 | 4 | 13 | 39 | 44 | 42 | 0 | 0 | 0 | 34 | 66 | 57 | 62 |
| Miranol HM | 0 | 0 | 0 | 19 | 38 | 43 | 40 | 0 | 0 | 0 | 14 | 46 | 58 | 60 |
| Miranol DM | | | 43 | 40 | 45 | 40 | 39 | | | 57 | 65 | 64 | 64 | 53 |

Table 22. Elongation of corn roots, in centimeters, measured 3 days after treatment with 7 concentrations of selected surfactants from the Ultrawet and Miranol families; data are averages of measurements from 3 seedlings

| Surfactant | Concentration | | | | | | |
|---|---|---|---|---|---|---|---|
| | 0.0 | .01 | .05 | .1 | .5 | 1.0 | 5.0 |
| Ultrawet DS | 21.6 | 17.0 | 7.4 | 0.5 | 0.0 | 0.0 | 0.0 |
| Ultrawet 30-DS | 17.1 | 14.6 | 5.2 | 1.1 | 0.0 | 0.0 | 0.0 |
| Ultrawet K | 22.2 | 13.4 | 12.1 | 0.2 | 0.0 | 0.0 | 0.0 |
| Ultrawet SK | 18.3 | 15.7 | 10.3 | 4.1 | 0.0 | 0.0 | 0.0 |
| Miranol CM | 19.6 | 17.2 | 8.8 | 4.4 | 0.4 | 0.4 | 0.0 |
| Miranol HM | 18.0 | 13.8 | 3.4 | 1.5 | 0.5 | 0.4 | 0.0 |

Foliar applications of the Ultrawets did not inhibit growth of soybeans completely. These growth responses are summarized in Tables 23 and 24. Of the Ultrawets tested, all reduced the dry matter yield of first trifoliates about 50 percent when treated with 1.0 percent, while at lower concentrations no effect was observed.

Miranols

Miranol CM, a derivative of coconut fatty acids, and Miranol HM, a derivative of lauric acid, were toxic to seed germination at higher concentrations; Miranol DM, a derivative of stearic acid, was considerably less toxic. Oats were most sensitive and corn least sensitive to the Miranols. Giant foxtail and radish were intermediate in sensitivity to the Miranols. Miranol CM was not as inhibitory to root elongation as was Miranol HM. However, at concentrations greater than 0.5 percent, little growth occurred when treated with either material. Data from these experiments are summarized in Tables 21 and 22. Foliar applications of Miranol HM and CM were toxic initially with the 1.0 percent concentration, but resulted in no appreciable decrease in dry weight. Treatment with Miranol DM resulted in an approximately 50 percent decrease in dry matter yield of trifoliate leaves. These responses are shown in Tables 23 and 24.

Ethomeens, Ethoquads, and Ethomids

The Ethomeen series of surfactants are tertiary amines having one fatty alkyl group, derived from various sources having 12 to 18 carbon atoms, and two polyoxyethylene groups attached to the nitrogen. In each compound the number or letter before the slash refers to the alkyl radical: C-coco amine, T-tallow amine, 18-stearyl amine, O-oleyl amide;

Table 23. Leaf injury ratings, 2 days after treatment, for soybeans treated with 4 concentrations of various surfactants of the Ultrawet and Miranol families; ratings are based on a 0-5 scale; data are means of 3 observations

| Surfactant | Concentration 1.0 | .1 | .01 | Ck |
|---|---|---|---|---|
| Ultrawet DS | 3 | 1 | 0 | 0 |
| Ultrawet 30-DS | 3 | 1 | 0 | 0 |
| Ultrawet K | 3 | 1 | 0 | 0 |
| Miranol HM | 3 | 0 | 0 | 0 |
| Miranol CM | 3 | 0 | 0 | 0 |
| Miranol DM | 3 | 0 | 0 | 0 |

Table 24. Dry weight in grams of soybean plant parts, cut off above the cotyledons, 14 days after treatment with 4 concentrations of various surfactants from the Ultrawet and Miranol families; each datum represents an average of 3 replications

| Surfactant | Concentration 1.0 | .1 | .01 | Ck |
|---|---|---|---|---|
| Ultrawet DS | .140 | .374 | .411 | .397 |
| Ultrawet 30-DS | .169 | .399 | .363 | .389 |
| Ultrawet K | .134 | .438 | .388 | .402 |
| Miranol HM | .330 | .475 | .359 | .360 |
| Miranol CM | .331 | .331 | .454 | .403 |
| Miranol DM | .150 | .361 | .319 | .491 |

the number after the slash, minus 10, refers to the number of polyoxyethylene groups per mole. Ethomeens 18/15, 18/25, and 18/60 exhibited a decrease in inhibition of germination as polyoxyethylene content was increased, as shown in Table 25. This pattern was evident with all species except radish. In the case of the Ethomeens, which included a tallow amine alkyl radical, there was a reversal of the usual trend of inhibition in relation to polyoxyethylene content. Ethomeen T/12, which contained 2 polyoxyethylene groups per mole, was slightly less toxic than Ethomeen T/15, which contained 5 polyoxyethylene groups per mole. Ethomeen 0/15, which contained an oleyl radical within its structure, and comparable amounts of polyoxyethylene to the T/15 and 18/15 derivatives, was slightly more toxic than was 18/15, the stearyl amine derivative. Essentially, 0/15 and T/15 gave similar responses. Seeds treated with members of the Ethoquad series of surfactants were injured to a greater extent when the alkyl group consisted of a coco- group (Ethoquad C/12) than when the alkyl was either an oleyl (Ethoquad 0/12) or stearyl (Ethoquad 18/12) group. All three members contained comparable amounts of polyoxyethylene. Ethomid 0/15, an oleyl derivative containing 5 moles of polyoxyethylene, was more toxic than Ethomid HT/60, a hydrogenated tallow amide containing 50 moles of polyoxyethylene.

Responses of corn roots to the Ethomeen, Ethoquad, and Ethomid series of surfactants paralleled closely the effects on seeds, as shown in Table 26. Of the stearyl amine derivatives within the Ethomeen series, the member containing the most polyoxyethylene (Ethomeen 18/60) was the least toxic. Ethomeen 18/15, which contained 5 moles of polyoxyethylene, was less toxic than Ethomeen 18/25, which contained 15 moles of

Table 25. Total number of seeds of corn, oats, radish, and giant foxtail germinating 7 days after treatment with 7 concentrations of selected surfactants from Ethomeen, Ethoquad, or Ethomid families; data are counts from 45 seeds, 3 replications of 15 seeds each for corn, oats, and radish; and 75 seeds, 3 replications of 25 seeds each for giant foxtail

| Surfactant | Concentration | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 5 | 1 | .5 | .1 | .05 | .01 | Ck | 5 | 1 | .5 | .1 | .05 | .01 | Ck |
| | Corn | | | | | | | Oats | | | | | | |
| Ethomeen 18/25 | 19 | 30 | 36 | 45 | 44 | 45 | 43 | 0 | 0 | 0 | 0 | 6 | 32 | 41 |
| Ethomeen 0/15 | 0 | 0 | 0 | 43 | 44 | 45 | 45 | 0 | 0 | 0 | 0 | 9 | 18 | 41 |
| Ethomeen T/15 | 0 | 5 | 15 | 44 | 45 | 45 | 44 | 0 | 0 | 0 | 1 | 10 | 23 | 36 |
| Ethomeen T/12 | 26 | 40 | 45 | 45 | 45 | 43 | 45 | 0 | 1 | 0 | 5 | 16 | 23 | 40 |
| Ethomeen 18/60 | 45 | 45 | 44 | 44 | 45 | 45 | 45 | 17 | 22 | 13 | 23 | 27 | 27 | 39 |
| Ethomeen 18/15 | 6 | 16 | 17 | 43 | 45 | 45 | 45 | 0 | 0 | 0 | 0 | 1 | 3 | 36 |
| Ethoquad C/12 | 0 | 0 | 10 | 45 | 44 | 45 | 45 | 0 | 0 | 0 | 2 | 11 | 24 | 39 |
| Ethoquad 18/12 | 7 | 23 | 45 | 43 | 45 | 45 | 45 | 0 | 0 | 1 | 15 | 18 | 20 | 37 |
| Ethoquad 0/12 | 0 | 7 | 34 | 45 | 45 | 45 | 45 | 0 | 0 | 0 | 16 | 26 | 37 | 44 |
| Ethomid 0/15 | 6 | 17 | 16 | 43 | 45 | 45 | 45 | 0 | 0 | 0 | 8 | 12 | 17 | 43 |
| Ethomid HT/60 | 13 | 43 | 44 | 45 | 45 | 45 | 45 | 30 | 26 | 30 | 28 | 25 | 39 | 42 |
| | Radish | | | | | | | Giant Foxtail | | | | | | |
| Ethomeen 18/25 | 0 | 0 | 0 | 23 | 33 | 40 | 42 | 0 | 0 | 0 | 50 | 62 | 56 | 63 |
| Ethomeen 0/15 | 0 | 0 | 0 | 28 | 34 | 45 | 44 | 0 | 0 | 1 | 55 | 63 | 63 | 61 |
| Ethomeen T/15 | 0 | 0 | 0 | 39 | 44 | 45 | 45 | 0 | 5 | 19 | 69 | 65 | 65 | 65 |
| Ethomeen T/12 | 0 | 11 | 19 | 44 | 41 | 41 | 44 | 0 | 29 | 52 | 57 | 60 | 67 | 67 |
| Ethomeen 18/60 | 44 | 44 | 44 | 44 | 45 | 45 | 44 | 49 | 64 | 63 | 59 | 60 | 63 | 62 |
| Ethomeen 18/15 | 0 | 0 | 0 | 24 | 39 | 42 | 43 | 0 | 0 | 0 | 16 | 54 | 66 | 69 |
| Ethoquad C/12 | 0 | 0 | 0 | 0 | 13 | 45 | 45 | 0 | 0 | 0 | 0 | 25 | 60 | 59 |
| Ethoquad 18/12 | 0 | 0 | 0 | 40 | 45 | 44 | 45 | 0 | 0 | 0 | 65 | 68 | 61 | 64 |
| Ethoquad 0/12 | 0 | 0 | 0 | 27 | 42 | 45 | 45 | 0 | 0 | 2 | 54 | 60 | 66 | 66 |
| Ethomid 0/15 | 32 | 35 | 42 | 44 | 45 | 43 | 45 | 48 | 57 | 62 | 56 | 59 | 64 | 58 |
| Ethomid HT/60 | 44 | 43 | 44 | 45 | 42 | 44 | 45 | 63 | 63 | 67 | 62 | 67 | 65 | 62 |

Table 26. Elongation of corn roots, in centimeters, measured 3 days after treatment with 7 concentrations of selected surfactants from the Ethomeen, Ethoquad, and Ethomid families; data are averages of measurements from 3 seedlings

| Surfactant | Concentration 0.0 | .01 | .05 | .1 | .5 | 1.0 | 5.0 |
|---|---|---|---|---|---|---|---|
| Ethomeen 18/25 | 21.8 | 10.2 | 6.4 | 1.3 | 0.0 | 0.1 | 0.2 |
| Ethomeen 18/15 | 16.7 | 14.3 | 9.9 | 7.4 | 0.8 | 1.1 | 0.1 |
| Ethomeen 18/60 | 18.5 | 16.4 | 15.1 | 11.0 | 5.2 | 4.5 | 4.0 |
| Ethomeen 0/15 | 16.6 | 10.2 | 6.5 | 2.0 | 0.2 | 0.0 | 0.1 |
| Ethomeen T/15 | 16.8 | 12.4 | 4.6 | 2.9 | 1.0 | 0.4 | 1.7 |
| Ethomeen T/12 | 20.5 | 13.9 | 7.8 | 4.7 | 1.5 | 0.3 | 0.1 |
| Ethoquad C/12 | 18.8 | 2.2 | 0.0 | 0.8 | 0.0 | 0.0 | 0.0 |
| Ethoquad O/12 | 16.2 | 5.9 | 1.8 | 0.6 | 0.0 | 0.0 | 0.2 |
| Ethoquad 18/12 | 16.7 | 12.4 | 3.8 | 1.8 | 0.2 | 0.0 | 0.0 |
| Ethomid O/15 | 16.8 | 16.6 | 15.8 | 15.9 | 16.1 | 11.7 | 9.6 |
| Ethomid HT/60 | 21.5 | 20.4 | 21.5 | 20.6 | 21.1 | 20.4 | 10.5 |

polyoxyethylene. Both the tallow and oleyl amine derived surfactants containing 5 moles of polyoxyethylene were more toxic to root elongation than was the stearyl amine derivative. Although the polyoxyethylene content of Ethomeen T/12 was less than that of Ethomeen T/15, two tallow amine derivatives, Ethomeen T/15 was considerably more inhibitory to root elongation than Ethomeen T/12. These observations are supported by an analysis of variance in Table 27.

Table 27. Analysis of variance for root elongation data taken from corn roots measured 3 days after treatment with Ethomeen T/15 and Ethomeen T/12 at each of 7 concentrations

| Source of variation | df | Sum of squares | Mean square | F values |
|---|---|---|---|---|
| Surfactant | 1 | 28.01 | 28.01 | 5.82* |
| Concentration | 6 | 1294.33 | 215.72 | 44.84** |
| Surfactant x Concentration | 6 | 34.35 | 5.72 | 1.18 |
| Error | 28 | 134.82 | 4.81 | |

*Denotes significant differences at P = 0.05.

**Denotes significant differences at P = 0.01.

The Ethoquad surfactants represent a series of polyethyoxylated quarternary ammonium salts formed by the addition of methyl chloride to Ethomeens (polyethyoxylated aliphatic amines). All of the members tested had 2 moles of polyoxyethylene and either coco- (Ethoquad C/12), oleyl (Ethoquad O/12), or a stearyl (Ethoquad 18/12) alkyl group. Ethoquad 18/12

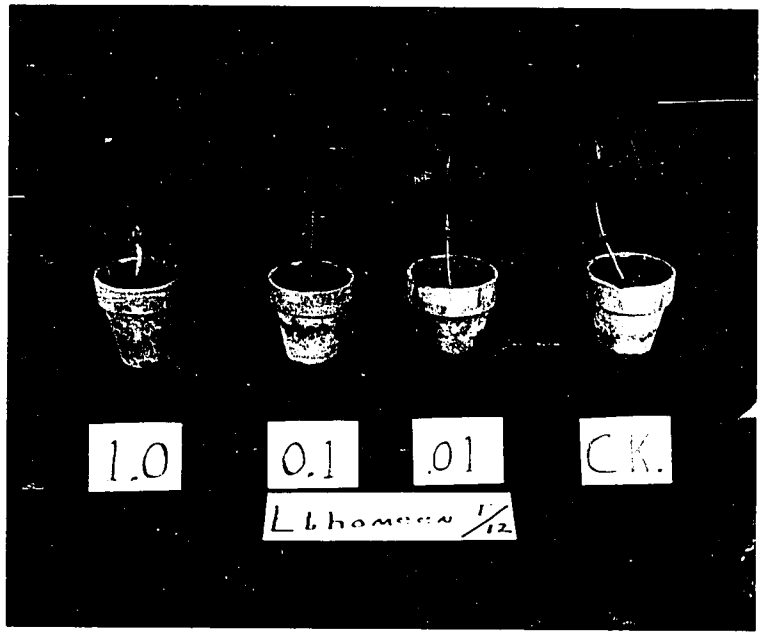
was substantially less inhibitory to root elongation than either of the other members of this series; however, this surfactant was slightly more toxic than Ethomeen T/12, the tallow amine derivative containing a comparable amount of polyoxyethylene. Ethoquad C/12 was the most potent member of this series, and Ethoquad 0/12 was only slightly less toxic.

The Ethomids, which are N,N-substituted fatty acid amides, were the least inhibitory to root elongation of any member of either of these 3 series of surfactants. Noticeable reductions in root elongation occurred at concentrations of 1.0 percent or greater with Ethomid 0/15 and at 5 percent with Ethomid HT/60. These effects of the Ethomeen, Ethoquad, and Ethomid surfactants on root elongation are summarized in Table 26.

Ethomid HT/60 had no effect on dry matter yield of soybeans when applied as a foliar treatment. Ethomid 0/15 reduced the total dry weight of trifoliate leaves only slightly. The Ethoquads produced a toxicity pattern quite similar to their effects on root elongation. No growth of soybean trifoliates occurred when treated with Ethoquads 0/12 or C/12 at 1.0 percent concentrations. Treatment with Ethoquad 18/12 reduced dry matter yield, but did not suppress growth completely. Within the Ethomeens at 1.0 percent, 18/60 produced no toxic effects, 18/25 reduced dry matter yields almost 50 percent, and 0/15, T/15, and T/12 inhibited growth completely. At lower concentrations, only Ethomeen 0/15 reduced growth appreciably. These observations are illustrated in Figure 15 and summarized in Tables 28 and 29.

Figure 15. Soybean injury as reflected by development of the first trifoliate leaf; photos taken 5 days after treatment with (a) Ethomeen T/12, (b) Ethomeen 18/25, or (c) Ethomeen 18/60 at 4 concentrations; differences in injury reflect a variation in chemical composition of either the hydrophobic or hydrophilic group

(a)




(b)

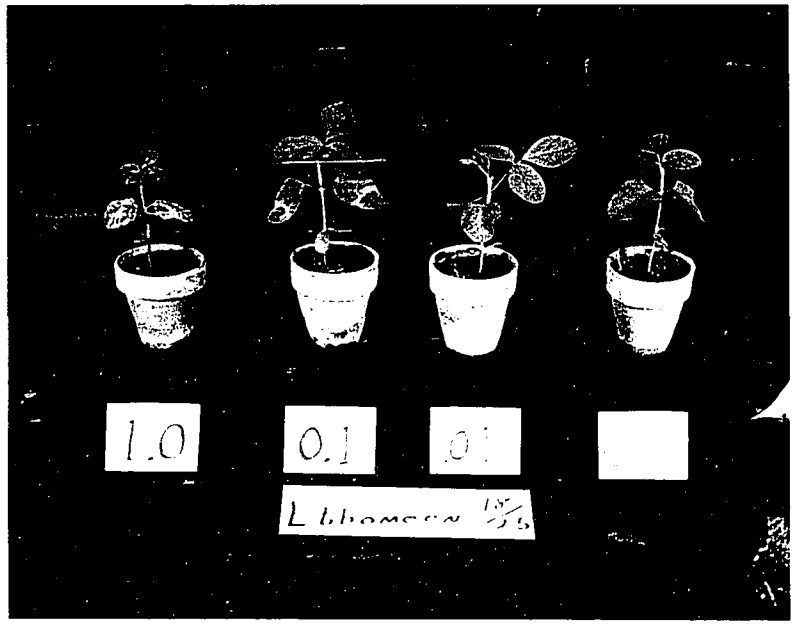


Figure 15, **(Continued)**

(c)

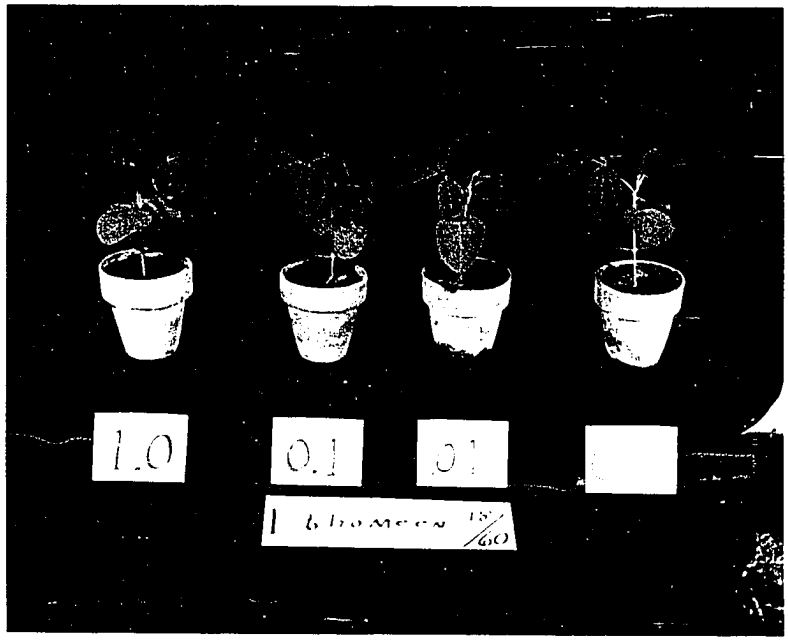


Table 28. Leaf injury ratings, 2 days after treatment, for soybeans treated with 4 concentrations of various surfactants of the Ethomid, Ethomeen, or Ethoquad families; ratings are based on a 0-5 scale; data are means of 3 observations

| Surfactant | 1.0 | .1 | .01 | Ck |
|---|---|---|---|---|
| Ethomid 0/15 | 2 | 1 | 0 | 0 |
| Ethomid HT/60 | 0 | 0 | 0 | 0 |
| Ethomeen 18/25 | 3 | 2 | 0 | 0 |
| Ethomeen 18/60 | 0 | 0 | 0 | 0 |
| Ethomeen 0/15 | 4 | 3 | 0 | 0 |
| Ethomeen T/15 | 4 | 2 | 1 | 0 |
| Ethomeen T/12 | 4 | 1 | 0 | 0 |
| Ethoquad 0/12 | 3 | 2 | 0 | 0 |
| Ethoquad C/12 | 3 | 2 | 0 | 0 |
| Ethoquad 18/12 | 3 | 2 | 0 | 0 |

Table 29. Dry weight in grams of soybean plant parts, cut off above the cotyledons, 14 days after treatment with 4 concentrations of various surfactants from the Ethomid, Ethomeen or Ethoquad families; each datum represents an average of 3 replications

| Surfactant | 1.0 | .1 | .01 | Ck |
|---|---|---|---|---|
| Ethomid 0/15 | .268 | .415 | .408 | .503 |
| Ethomid HT/60 | .388 | .550 | .441 | .451 |
| Ethomeen 18/25 | .193 | .301 | .358 | .282 |
| Ethomeen 18/60 | .383 | .441 | .388 | .425 |
| Ethomeen 0/15 | .000 | .053 | .352 | .335 |
| Ethomeen T/15 | .000 | .373 | .356 | .423 |
| Ethomeen T/12 | .000 | .343 | .423 | .412 |
| Ethoquad 0/12 | .000 | .316 | .394 | .325 |
| Ethoquad C/12 | .000 | .267 | .432 | .418 |
| Ethoquad 18/12 | .073 | .287 | .352 | .351 |

Alkanols

Within the Alkanol series of surfactants, there was a notable decrease in inhibition of germination with an increase in the number of polyoxyethylene groups per mole of surfactants, as shown in Table 30. Alkanol HC, which contained the longest polyoxyethylene chain, was least toxic to all species tested. Oats were considerably more sensitive than any of the other seeds. Response of corn roots to the Alkanols, as shown in Table 31 does not indicate a clear-cut pattern of toxicity with relation to chemical structure. Generally, members of this series of surfactants inhibited elongation of corn roots equally. Alkanol OA, which appeared only slightly less toxic to corn roots than other members of the series, was the most inhibitory to growth when applied as a foliage spray. Other members of this series reduced growth of the first trifoliate leaf substantially with treatments of 1.0 percent concentrations; however, lower concentrations gave slight, if any, reductions in growth. These responses are summarized in Tables 32 and 33.

Nonisols

In general, the Nonisols, which are esters of polyethylene glycol mono- and di- fatty acids, were not inhibitory to germination, as shown in Table 30. At concentrations of 1.0 percent or less, there was no inhibition of germination with the species tested. Oats were generally most sensitive, especially to the lauric acid derivatives, Nonisol 100, 110, and 250. The Nonisols had little effect on elongation of corn roots at the concentrations tested, except for Nonisol 100, which was toxic at the 5 percent concentration. Foliar applications of the Nonisols

Table 30. Total number of seeds of corn, oats, radish, and giant foxtail germinating 7 days after treatment with 7 concentrations of selected surfactants from the Alkanol and Nonisol families; data are counts from 45 seeds, 3 replications of 15 seeds each for corn, oats, and radish; and 75 seeds, 3 replications of 25 seeds each for giant foxtail

| Surfactant | Concentration | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 5 | 1 | .5 | .1 | .05 | .01 | Ck | 5 | 1 | .5 | .1 | .05 | .01 | Ck |
| | Corn | | | | | | | Oats | | | | | | |
| Alkanol OA | 37 | 37 | 45 | 44 | 42 | 42 | 43 | 5 | 13 | 12 | 14 | 13 | 15 | 40 |
| Alkanol OJ | 21 | 12 | 10 | 20 | 42 | 45 | 45 | 0 | 0 | 0 | 0 | 2 | 17 | 36 |
| Alkanol HC | 44 | 45 | 44 | 40 | 44 | 43 | 43 | 10 | 7 | 6 | 15 | 17 | 22 | 36 |
| Alkanol OP | 29 | 31 | 38 | 44 | 44 | 45 | 45 | 0 | 0 | 5 | 4 | 14 | 16 | 40 |
| Nonisol 100 | 36 | 45 | 45 | 43 | 44 | 45 | 45 | 0 | 0 | 13 | 18 | 20 | 37 | 38 |
| Nonisol 200 | 44 | 39 | 44 | 45 | 45 | 45 | 45 | 4 | 10 | 10 | 20 | 30 | 27 | 43 |
| Nonisol 110 | 35 | 45 | 45 | 45 | 45 | 45 | 45 | 0 | 3 | 3 | 18 | 35 | 33 | 40 |
| Nonisol 210 | 44 | 45 | 45 | 45 | 45 | 45 | 45 | 4 | 11 | 16 | 22 | 19 | 30 | 33 |
| Nonisol 250 | 25 | 40 | 43 | 45 | 45 | 45 | 45 | 0 | 2 | 12 | 14 | 32 | 32 | 42 |
| Nonisol 300 | 45 | 45 | 44 | 44 | 45 | 45 | 44 | 4 | 15 | 22 | 18 | 23 | 31 | 42 |
| | Radish | | | | | | | Giant Foxtail | | | | | | |
| Alkanol OA | 44 | 45 | 45 | 45 | 45 | 44 | 44 | 40 | 64 | 58 | 63 | 66 | 60 | 63 |
| Alkanol OJ | 27 | 23 | 28 | 41 | 40 | 42 | 42 | 0 | 45 | 57 | 63 | 64 | 63 | 63 |
| Alkanol HC | 39 | 41 | 43 | 45 | 45 | 45 | 45 | 64 | 65 | 62 | 64 | 65 | 62 | 73 |
| Alkanol OP | 28 | 32 | 38 | 39 | 42 | 41 | 44 | 54 | 66 | 64 | 63 | 66 | 66 | 66 |
| Nonisol 100 | 43 | 41 | 43 | 42 | 42 | 45 | 43 | 9 | 52 | 66 | 55 | 48 | 63 | 60 |
| Nonisol 200 | 41 | 44 | 43 | 44 | 45 | 42 | 44 | 37 | 62 | 64 | 66 | 65 | 68 | 61 |
| Nonisol 110 | 43 | 42 | 44 | 43 | 45 | 42 | 41 | 33 | 58 | 56 | 58 | 57 | 58 | 52 |
| Nonisol 210 | 28 | 41 | 43 | 45 | 42 | 45 | 44 | 40 | 55 | 57 | 54 | 55 | 56 | 55 |
| Nonisol 250 | 21 | 42 | 43 | 43 | 40 | 43 | 44 | 5 | 44 | 49 | 57 | 53 | 57 | 47 |
| Nonisol 300 | 44 | 44 | 44 | 45 | 43 | 45 | 45 | 64 | 64 | 59 | 66 | 62 | 60 | 70 |

Table 31. Elongation of corn roots, in centimeters, measured 3 days after treatment with 7 concentrations of selected surfactants from the Alkanol and Nonisol families; data are averages of measurements from 3 seedlings

| Surfactant | Concentration 0.0 | .01 | .05 | .1 | .5 | 1.0 | 5.0 |
|---|---|---|---|---|---|---|---|
| Alkanol OA | 15.7 | 15.7 | 15.5 | 13.2 | 15.7 | 13.2 | 10.4 |
| Alkanol OJ | 15.0 | 13.1 | 12.3 | 11.0 | 10.4 | 7.2 | 5.3 |
| Alkanol HC | 15.5 | 14.7 | 10.7 | 14.5 | 10.8 | 7.8 | 6.9 |
| Alkanol OP | 15.4 | 12.4 | 13.0 | 11.1 | 10.8 | 9.0 | 7.2 |
| Nonisol 100 | 16.6 | 17.6 | 16.3 | 15.7 | 16.7 | 13.0 | 6.1 |
| Nonisol 110 | 18.7 | 13.4 | 17.0 | 19.3 | 14.8 | 15.2 | 15.0 |
| Nonisol 200 | 17.0 | 16.9 | 19.1 | 17.9 | 18.4 | 12.6 | 13.1 |
| Nonisol 210 | 16.7 | 17.9 | 20.1 | 18.7 | 16.6 | 17.4 | 17.9 |
| Nonisol 250 | 15.7 | 17.8 | 19.6 | 19.4 | 16.1 | 18.3 | 13.7 |
| Nonisol 300 | 17.3 | 17.0 | 16.7 | 17.3 | 15.3 | 13.3 | 16.1 |

Table 32. Leaf injury ratings, 2 days after treatment, for soybeans treated with 4 concentrations of various surfactants of the Alkanol and Nonisol families; ratings are based on a 0-5 scale; data are means of 3 observations

| Surfactant | Concentration 1.0 | .1 | .01 | Ck |
|---|---|---|---|---|
| Alkanol OA | 4 | 3 | 1 | 0 |
| Alkanol HC | 3 | 1 | 0 | 0 |
| Alkanol OP | 3 | 1 | 0 | 0 |
| Alkanol OJ | 3 | 1 | 0 | 0 |
| Nonisol 100 | 2 | 0 | 0 | 0 |
| Nonisol 110 | 2 | 0 | 0 | 0 |
| Nonisol 200 | 2 | 0 | 0 | 0 |
| Nonisol 210 | 2 | 0 | 0 | 0 |
| Nonisol 250 | 0 | 0 | 0 | 0 |
| Nonisol 300 | 0 | 0 | 0 | 0 |

Table 33. Dry weight in grams of soybean plant parts cut off above the cotyledons, 14 days after treatment with 4 concentrations of various surfactants from the Alkanol and Nonisol families; each datum represents an average of 3 replications

| Surfactant | Concentration 1.0 | .1 | .01 | Ck |
|---|---|---|---|---|
| Alkanol OA | .000 | .041 | .213 | .251 |
| Alkanol HC | .056 | .248 | .268 | .309 |
| Alkanol OP | .079 | .206 | .305 | .282 |
| Alkanol OJ | .066 | .218 | .284 | .280 |
| Nonisol 100 | .166 | .219 | .317 | .233 |
| Nonisol 110 | .206 | .287 | .255 | .243 |
| Nonisol 200 | .193 | .273 | .221 | .196 |
| Nonisol 210 | .202 | .274 | .229 | .183 |
| Nonisol 250 | .244 | .323 | .243 | .192 |
| Nonisol 300 | .208 | .203 | .205 | .160 |

had little effect on dry matter yield of soybean trifoliates at concentrations up to 1.0 percent. The effects of the Nonisols on root elongation and on soybean leaves are summarized in Tables 31, 32, and 33.

Tergitols

Tergitol anionics were extremely inhibitory to germination of all plant species tested, as indicated in Table 34. Tergitol TMN, a trimethyl nonanol containing 6 moles of polyoxyethylene, inhibited germination of oats at concentrations as low as 0.01 percent; Tergitol 08, sodium 2-ethyl hexyl sulfate, was generally less inhibitory. Tergitol 7, sodium heptadecyl sulfate, was slightly more toxic than Tergitol 4, the sodium tetradecyl sulfate; the former inhibited completely germination of oats at concentrations as low as 0.01 percent. Tergitol P-28, sodium di-2-ethyl hexyl phosphate, was also extremely toxic. Tergitol NP-33, nonionic nonyl phenol containing 13 moles of polyoxyethylene, was substantially less toxic than other Tergitols, especially to corn, radish, and giant foxtail seeds.

The responses of corn roots to the Tergitol surfactants are recorded in Table 35. Tergitol 7 reduced the elongation of corn roots by as much as 50 percent with 0.01 percent concentration. Tergitol P-28 also resulted in substantial reductions in root elongation at concentrations as low as 0.01 percent. Considerable reduction occurred with Tergitol 4 and Tergitol TMN at concentrations of 0.05 percent or more. Tergitol 08 and the nonionic NP-33 were less toxic than other members, and appreciable reductions in total root length occurred only with concentrations of 0.5 percent or more.

Table 34. Total number of seeds of corn, oats, radish, and giant foxtail germinating 7 days after treatment with 7 concentrations of selected surfactants from the Tergitol family; data are counts from 45 seeds, 3 replications of 15 seeds each for corn, oats, and radish; and 75 seeds, 3 replications of 25 seeds each for giant foxtail

| Surfactant | Concentration | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 5 | 1 | .5 | .1 | .05 | .01 | Ck | 5 | 1 | .5 | .1 | .05 | .01 | Ck |
| | Corn | | | | | | | Oats | | | | | | |
| Tergitol TMN | 0 | 0 | 0 | 8 | 43 | 44 | 45 | 0 | 0 | 0 | 0 | 0 | 13 | 34 |
| Tergitol 08 | 0 | 0 | 19 | 45 | 45 | 45 | 45 | 0 | 0 | 0 | 37 | 40 | 41 | 38 |
| Tergitol P-28 | 0 | 0 | 0 | 35 | 45 | 45 | 45 | 0 | 0 | 0 | 0 | 0 | 21 | 39 |
| Tergitol NP-33 | 33 | 39 | 30 | 33 | 45 | 40 | 45 | 0 | 0 | 0 | 2 | 0 | 11 | 41 |
| Tergitol 7 | 0 | 0 | 0 | 7 | 44 | 45 | 45 | 0 | 0 | 0 | 0 | 0 | 0 | 39 |
| Tergitol 4 | 0 | 0 | 0 | 42 | 45 | 43 | 45 | 0 | 0 | 0 | 0 | 0 | 14 | 34 |
| | Radish | | | | | | | Giant Foxtail | | | | | | |
| Tergitol TMN | 0 | 0 | 2 | 5 | 17 | 44 | 42 | 0 | 0 | 0 | 35 | 60 | 63 | 61 |
| Tergitol 08 | 0 | 0 | 34 | 44 | 43 | 40 | 44 | 0 | 0 | 40 | 62 | 60 | 60 | 60 |
| Tergitol P-28 | 0 | 0 | 0 | 0 | 15 | 40 | 42 | 0 | 0 | 0 | 0 | 8 | 56 | 69 |
| Tergitol NP-33 | 31 | 35 | 41 | 42 | 42 | 44 | 44 | 46 | 62 | 57 | 58 | 62 | 61 | 70 |
| Tergitol 7 | 0 | 0 | 0 | 12 | 32 | 39 | 42 | 0 | 0 | 0 | 0 | 0 | 40 | 54 |
| Tergitol 4 | 0 | 0 | 0 | 5 | 36 | 45 | 45 | 0 | 0 | 0 | 0 | 0 | 50 | 61 |

Table 35. Elongation of corn roots, in centimeters, measured 3 days after treatment with 7 concentrations of selected surfactants of the Tergitol family; data are averages of measurements from 3 seedlings

| Surfactant | Concentration | | | | | | |
|---|---|---|---|---|---|---|---|
| | 0.0 | .01 | .05 | .1 | .5 | 1.0 | 5.0 |
| Tergitol 4 | 21.1 | 19.3 | 9.1 | 0.5 | 0.0 | 0.1 | 0.0 |
| Tergitol 7 | 18.7 | 8.1 | 0.4 | 0.8 | 0.2 | 0.1 | 0.1 |
| Tergitol 08 | 18.4 | 17.0 | 19.4 | 13.6 | 0.9 | 0.1 | 0.0 |
| Tergitol TMN | 16.0 | 20.1 | 0.0 | 4.0 | 0.0 | 0.0 | 0.0 |
| Tergitol P-28 | 16.4 | 12.9 | 0.8 | 0.0 | 0.0 | 0.0 | 0.0 |
| Tergitol NP-33 | 18.4 | 14.7 | 13.2 | 11.4 | 5.5 | 8.6 | 5.0 |

Foliar application of the Tergitols at 1.0 percent resulted in reduction of dry matter yields of trifoliates; Tergitol 4, 7, 08, and TMN permitted no growth. Soybeans treated with Tergitol P-28 or TMN produced only a slight amount of dry matter in the new growth of trifoliate leaves. These effects are summarized in Tables 36 and 37.

Alrosols

Within the Alrosols, which are diethanolamine fatty acid condensates, the most toxic member to seed germination was Alrosol C, a capric acid derivative; the least toxic was Alrosol O, an oleic acid derivative. Alrosol, a coco- diethanol amide, and Alrosol B, a vegetable grade coco-diethanol amide, were intermediate in toxicity with Alrosol being only slightly more inhibitory than Alrosol B. Oats were, by far, the most sensitive of the species tested. These data are summarized in Table 38. The Alrosols were generally moderate in toxicity to corn roots, which paralleled closely the patterns of germination inhibition, as shown in Table 39. Alrosol C was the most toxic, inhibiting growth by as much as 50 percent at 0.05 percent concentration. Although Alrosol and Alrosol B reduced growth of roots by approximately 50 percent at 0.05 percent or greater concentrations, these materials permitted moderate growth at higher concentrations. Alrosol O was the least toxic material in this group; however, treatments with concentrations of 0.5 percent or greater produced a substantial decrease in root elongation.

Alrosol and Alrosol C applied as foliar treatments completely inhibited growth with 1.0 percent concentrations. Alrosol O-treated plants made only nominal growth. Plants treated with Alrosol B and Alrosol S,

Table 36. Leaf injury ratings, 2 days after treatment, for soybeans treated with 4 concentrations of various surfactants of the Tergitol family; ratings are based on a 0-5 scale; data are means of 3 observations

| Surfactant | Concentration 1.0 | .1 | .01 | Ck |
|---|---|---|---|---|
| Tergitol 08 | 4 | 2 | 0 | 0 |
| Tergitol 4 | 4 | 2 | 0 | 0 |
| Tergitol 7 | 4 | 1 | 0 | 0 |
| Tergitol P-28 | 4 | 2 | 0 | 0 |
| Tergitol NP-33 | 3 | 2 | 0 | 0 |
| Tergitol TMN | 4 | 2 | 0 | 0 |

Table 37. Dry weight in grams of soybean plant parts, cut off above the cotyledons, 14 days after treatment with 4 concentrations of various surfactants from the Tergitol family; each datum represents an average of 3 replications

| Surfactant | Concentration 1.0 | .1 | .01 | Ck |
|---|---|---|---|---|
| Tergitol 08 | .000 | .382 | .436 | .363 |
| Tergitol 4 | .000 | .268 | .391 | .427 |
| Tergitol 7 | .000 | .354 | .485 | .388 |
| Tergitol P-28 | .051 | .346 | .463 | .443 |
| Tergitol NP-33 | .040 | .260 | .463 | .398 |
| Tergitol TMN | .000 | .250 | .357 | .412 |

Table 38. Total number of seeds of corn, oats, radish, and giant foxtail germinating 7 days after treatment with 7 concentrations of selected surfactants from the Alrosol and Solulan families; data are counts from 45 seeds, 3 replications of 15 seeds each for corn, oats, and radish; and 75 seeds, 3 replications of 25 seeds each for giant foxtail

| Surfactant | Concentration | | | | | | | Concentration | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 5 | 1 | .5 | .1 | .05 | .01 | Ck | 5 | 1 | .5 | .1 | .05 | .01 | Ck |
| | Corn | | | | | | | Oats | | | | | | |
| Alrosol O | 16 | 39 | 44 | 45 | 40 | 45 | 45 | 0 | 0 | 0 | 0 | 3 | 18 | 40 |
| Alrosol B | 1 | 11 | 9 | 45 | 44 | 45 | 45 | 0 | 0 | 0 | 7 | 3 | 15 | 40 |
| Alrosol | 0 | 5 | 13 | 40 | 44 | 45 | 44 | 0 | 0 | 0 | 0 | 2 | 15 | 38 |
| Alrosol C | 0 | 0 | 0 | 40 | 44 | 45 | 44 | 0 | 0 | 0 | 0 | 0 | 38 | 42 |
| Solulan 98 | 8 | 21 | 29 | 45 | 45 | 45 | 45 | 0 | 2 | 4 | 14 | 23 | 32 | 36 |
| Solulan C24 | 45 | 45 | 45 | 45 | 44 | 45 | 45 | 14 | 15 | 15 | 20 | 20 | 32 | 38 |
| Solulan 25 | 41 | 45 | 43 | 45 | 45 | 45 | 45 | 2 | 3 | 5 | 37 | 40 | 40 | 40 |
| Solulan 75 | 41 | 45 | 44 | 45 | 45 | 45 | 45 | 32 | 32 | 18 | 32 | 34 | 37 | 37 |
| | Radish | | | | | | | Giant Foxtail | | | | | | |
| Alrosol O | 8 | 41 | 41 | 42 | 43 | 41 | 44 | 0 | 50 | 58 | 62 | 56 | 55 | 63 |
| Alrosol B | 0 | 8 | 35 | 43 | 41 | 41 | 40 | 0 | 3 | 42 | 65 | 53 | 62 | 61 |
| Alrosol | 0 | 12 | 10 | 41 | 38 | 44 | 42 | 0 | 0 | 9 | 35 | 58 | 58 | 60 |
| Alrosol C | 0 | 0 | 0 | 44 | 41 | 41 | 42 | 0 | 0 | 0 | 21 | 51 | 63 | 60 |
| Solulan 98 | 45 | 44 | 44 | 45 | 45 | 45 | 45 | 27 | 61 | 64 | 66 | 63 | 65 | 61 |
| Solulan C24 | 36 | 37 | 38 | 36 | 34 | 35 | 41 | 39 | 66 | 62 | 67 | 57 | 62 | 60 |
| Solulan 25 | 11 | 14 | 25 | 35 | 38 | 34 | 41 | 47 | 59 | 65 | 51 | 63 | 60 | 66 |
| Solulan 75 | 39 | 34 | 43 | 42 | 38 | 44 | 42 | 47 | 51 | 52 | 59 | 62 | 60 | 56 |

Table 39. Elongation of corn roots, in centimeters, measured 3 days after treatment with 7 concentrations of selected surfactants from the Alrosol and Solulan families; data are averages of measurements from 3 seedlings

| Surfactant | Concentration 0.0 | .01 | .05 | .1 | .5 | 1.0 | 5.0 |
|---|---|---|---|---|---|---|---|
| Alrosol | 18.3 | 14.3 | 11.2 | 5.9 | 3.5 | 1.2 | 0.5 |
| Alrosol C | 19.5 | 16.9 | 11.1 | 2.9 | 0.0 | 0.0 | 0.0 |
| Alrosol O | 19.1 | 16.7 | 14.6 | 14.5 | 10.4 | 8.6 | 1.3 |
| Alrosol B | 16.4 | 14.6 | 14.4 | 13.2 | 3.3 | 1.3 | 0.1 |
| Solulan 75 | 17.1 | 19.1 | 16.3 | 18.9 | 18.2 | 17.0 | 17.5 |
| Solulan 25 | 18.3 | 20.1 | 16.5 | 16.2 | 10.9 | 14.2 | 11.7 |
| Solulan C24 | 18.5 | 19.4 | 17.5 | 16.3 | 16.1 | 13.7 | 13.8 |
| Solulan 98 | 18.9 | 18.1 | 20.4 | 16.9 | 15.7 | 18.2 | 15.2 |

a stearic acid diethanolamide, made normal growth. No effects on final weight of trifoliates were observed with concentrations less than 1 percent. These effects are presented in Tables 40 and 41.

Solulans

Seeds treated with members of the Solulan surfactants reflected a low level of toxicity for members of this series, as shown in Table 38. Solulan 98, a polyoxyethylene derivative of lanolin which contained 10 moles of polyoxyethylene, was the most toxic member of the Solulans as indicated by seed germination tests on corn, oats, and giant foxtail. Radishes were not affected by Solulan 98. Solulan C24, a cholesterol derivative which contained 24 moles of polyoxyethylene, and Solulan 75, a lanolin derivative containing 75 moles of polyoxyethylene, had little, if any, effect on the species tested, with the exception of oats, which were inhibited at higher concentrations. Solulan 25, a lanolin alcohol derivative containing 25 moles of polyoxyethylene, had no effect on corn or giant foxtail. Oats and radishes were inhibited at higher concentrations. Data in Table 39 indicated that inhibition of root elongation by members of the Solulan surfactants was negligible. Growth of roots treated with Solulan 75 and 98 at concentrations up to 5.0 percent was equal to that of untreated checks. Solulan 25 and C24 reduced total elongation only slightly when applied at 1.0 and 5.0 percent concentrations. Foliar applications with concentrations up to 1.0 percent of the Solulans resulted in no appreciable reduction in dry matter yield, as shown in Tables 40 and 41. Growth of seedlings treated with Solulan C24 at 1.0 percent was only slightly reduced.

Table 40. Leaf injury ratings, 2 days after treatment, for soybeans treated with 4 concentrations of various surfactants of the Alrosol and Solulan families; ratings are based on a 0-5 scale; data are means of 3 observations

| Surfactant | Concentration 1.0 | .1 | .01 | Ck |
|---|---|---|---|---|
| Alrosol | 3 | 0 | 0 | 0 |
| Alrosol B | 2 | 0 | 0 | 0 |
| Alrosol C | 3 | 1 | 0 | 0 |
| Alrosol O | 2 | 0 | 0 | 0 |
| Alrosol S | 0 | 0 | 0 | 0 |
| Solulan 25 | 3 | 0 | 0 | 0 |
| Solulan 75 | 1 | 0 | 0 | 0 |
| Solulan 98 | 1 | 0 | 0 | 0 |
| Solulan C24 | 2 | 1 | 0 | 0 |

Table 41. Dry weight in grams of soybean plant parts, cut off above the cotyledons, 14 days after treatment with 4 concentrations of various surfactants from the Alrosol and Solulan families; each datum represents an average of 3 replications

| Surfactant | Concentration 1.0 | .1 | .01 | Ck |
|---|---|---|---|---|
| Alrosol | .000 | .193 | .213 | .172 |
| Alrosol B | .188 | .234 | .215 | .206 |
| Alrosol C | .000 | .211 | .288 | .241 |
| Alrosol O | .056 | .229 | .255 | .237 |
| Alrosol S | .229 | .205 | .262 | .241 |
| Solulan 25 | .292 | .386 | .448 | .421 |
| Solulan 75 | .279 | .394 | .305 | .458 |
| Solulan 98 | .403 | .442 | .370 | .387 |
| Solulan C24 | .255 | .276 | .369 | .334 |

Carbowaxes

Carbowaxes, which are polyethylene glycols differing in molecular weight, were not inhibitory to germination of any of the species tested at concentrations up to 5.0 percent; also, there was no appreciable reduction in root elongation with any of the concentrations tested. Neither Carbowax 300, 400, nor 600 reduced the dry matter yield of soybean trifoliates when applied as a foliar application. The responses of various plant tissues to Carbowaxes are presented in Tables 42, 43, 44, and 45.

Emcols

The Emcol emulsifiers were slightly inhibitory to the germination of all species tested, as shown in Table 42. On oats and giant foxtail, HA was most inhibitory with HB and HC decreasing in toxicity in that order. The response of corn roots to the Emcols, shown in Table 43, revealed little difference in activity among the Emcols. Only at concentrations greater than 0.1 percent were substantial reductions in total length measured. Foliar applications of Emcol HA and Emcol HB at 1.0 percent or less to soybean leaves, caused no reduction in dry weight of new trifoliates. Emcol HC reduced the growth of soybeans slightly at 1.0 percent. None of the members caused reduction in dry weight when applied at concentrations of 0.1 percent or less. These results are summarized in Tables 44 and 45.

Miscellaneous surfactants

Alrodynes 315 and 6104, polyoxyethylene glycol fatty esters, are multipurpose agricultural emulsifiers. Results, as shown in Table 46, indicated a low degree of toxicity of these materials to seed germination. These

Table 42. Total number of seeds of corn, oats, radish, and giant foxtail germinating 7 days after treatment with 7 concentrations of selected surfactants from the Carbowax and Emcol families; data are counts from 45 seeds, 3 replications of 15 seeds each for corn, oats, and radish; and 75 seeds, 3 replications of 25 seeds each for giant foxtail

| Surfactant | Concentration | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 5 | 1 | .5 | .1 | .05 | .01 | Ck | 5 | 1 | .5 | .1 | .05 | .01 | Ck |
| | Corn | | | | | | | Oats | | | | | | |
| Carbowax 300 | 42 | 45 | 45 | 45 | 45 | 45 | 44 | 43 | 38 | 40 | 36 | 38 | 36 | 40 |
| Carbowax 400 | 45 | 45 | 45 | 45 | 44 | 45 | 45 | 43 | 44 | 42 | 40 | 42 | 44 | 42 |
| Carbowax 600 | 46 | 45 | 45 | 45 | 45 | 45 | 45 | 37 | 38 | 40 | 37 | 40 | 38 | 40 |
| Emcol HB | 0 | 3 | 12 | 45 | 45 | 45 | 45 | 0 | 0 | 0 | 2 | 5 | 12 | 36 |
| Emcol HA | 0 | 15 | 28 | 45 | 45 | 45 | 45 | 0 | 0 | 1 | 0 | 3 | 7 | 31 |
| Emcol HC | 0 | 12 | 18 | 45 | 45 | 45 | 45 | 0 | 0 | 0 | 9 | 6 | 41 | 43 |
| | Radish | | | | | | | Giant Foxtail | | | | | | |
| Carbowax 300 | 38 | 29 | 40 | 43 | 30 | 42 | 32 | 45 | 61 | 50 | 55 | 57 | 60 | 60 |
| Carbowax 400 | 40 | 42 | 44 | 45 | 43 | 43 | 41 | 56 | 59 | 64 | 66 | 71 | 63 | 62 |
| Carbowax 600 | 43 | 45 | 44 | 42 | 43 | 43 | 44 | 42 | 60 | 50 | 58 | 58 | 60 | 56 |
| Emcol HB | 0 | 26 | 35 | 43 | 45 | 44 | 45 | 0 | 10 | 17 | 12 | 21 | 35 | 35 |
| Emcol HA | 0 | 30 | 41 | 44 | 45 | 44 | 43 | 0 | 3 | 11 | 26 | 19 | 48 | 51 |
| Emcol HC | 0 | 39 | 37 | 44 | 42 | 45 | 44 | 0 | 25 | 47 | 61 | 55 | 58 | 58 |

Table 43. Elongation of corn roots, in centimeters, measured 3 days after treatment with 7 concentrations of selected surfactants from the Carbowax and Emcol families; data are averages of measurements from 3 seedlings

| Surfactant | Concentration 0.0 | .01 | .05 | .1 | .5 | 1.0 | 5.0 |
|---|---|---|---|---|---|---|---|
| Carbowax 300 | 17.5 | 18.1 | 21.3 | 18.2 | 17.8 | 18.5 | 16.4 |
| Carbowax 400 | 19.7 | 18.5 | 18.6 | 20.9 | 16.0 | 19.3 | 16.9 |
| Carbowax 600 | 18.2 | 19.0 | 18.1 | 19.2 | 17.2 | 16.3 | 18.0 |
| Emcol HA | 15.3 | 15.6 | 12.3 | 8.4 | 3.3 | 0.8 | 0.2 |
| Emcol HB | 15.9 | 16.6 | 16.0 | 5.5 | 3.1 | 1.6 | 0.0 |
| Emcol HC | 16.2 | 15.7 | 14.4 | 10.0 | 4.2 | 1.3 | 0.2 |

Table 44. Leaf injury ratings, 2 days after treatment, for soybeans treated with 4 concentrations of various surfactants of the Carbowax and Emcol families; ratings are based on a 0-5 scale; data are means of 3 observations

| Surfactant | Concentration 1.0 | .1 | .01 | Ck |
|---|---|---|---|---|
| Carbowax 300 | 0 | 0 | 0 | 0 |
| Carbowax 400 | 0 | 0 | 0 | 0 |
| Carbowax 600 | 0 | 0 | 0 | 0 |
| Emcol HA | 0 | 0 | 0 | 0 |
| Emcol HB | 0 | 0 | 0 | 0 |
| Emcol HC | 1 | 0 | 0 | 0 |

Table 45. Dry weight in grams of soybean plant parts, cut off above the cotyledons, 14 days after treatment with 4 concentrations of various surfactants from the Carbowax and Emcol families; each datum represents an average of 3 replications

| Surfactant | Concentration 1.0 | .1 | .01 | Ck |
|---|---|---|---|---|
| Carbowax 300 | .518 | .448 | .375 | .403 |
| Carbowax 400 | .406 | .411 | .357 | .373 |
| Carbowax 600 | .371 | .387 | .363 | .394 |
| Emcol HA | .337 | .342 | .394 | .393 |
| Emcol HB | .281 | .326 | .418 | .379 |
| Emcol HC | .233 | .336 | .361 | .369 |

Table 46. Total number of seeds of corn, oats, radish, and giant foxtail germinating 7 days after treatment with 7 concentrations of selected surfactants; data are counts from 45 seeds, 3 replications of 15 seeds each for corn, oats, and radish; and 75 seeds, 3 replications of 25 seeds each for giant foxtail

| Surfactant | Concentration | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 5 | 1 | .5 | .1 | .05 | .01 | Ck | 5 | 1 | .5 | .1 | .05 | .01 | Ck |
| | Corn | | | | | | | Oats | | | | | | |
| Alrodyne 6104 | 41 | 43 | 35 | 44 | 44 | 45 | 44 | 1 | 6 | 10 | 14 | 26 | 21 | 43 |
| Alrodyne 315 | 44 | 45 | 45 | 45 | 45 | 44 | 45 | 0 | 3 | 13 | 19 | 26 | 23 | 42 |
| Toximul R | 0 | 0 | 1 | 35 | 43 | 45 | 45 | 0 | 0 | 0 | 0 | 6 | 12 | 40 |
| Toximul S | 0 | 13 | 11 | 33 | 45 | 45 | 45 | 0 | 0 | 0 | 0 | 4 | 20 | 42 |
| Tetrosan 3,4-D | 0 | 12 | 31 | 45 | 45 | 45 | 45 | 0 | 0 | 0 | 4 | 8 | 30 | 41 |
| Super Amide GR | 0 | 5 | 7 | 30 | 44 | 45 | 45 | 0 | 0 | 0 | 0 | 1 | 17 | 39 |
| | Radish | | | | | | | Giant Foxtail | | | | | | |
| Alrodyne 6104 | 29 | 42 | 42 | 44 | 44 | 42 | 43 | 0 | 52 | 65 | 53 | 60 | 57 | 52 |
| Alrodyne 315 | 8 | 44 | 43 | 44 | 44 | 43 | 43 | 0 | 42 | 55 | 58 | 59 | 62 | 66 |
| Toximul R | 0 | 0 | 2 | 29 | 39 | 42 | 45 | 0 | 0 | 0 | 11 | 24 | 51 | 56 |
| Toximul S | 0 | 16 | 25 | 41 | 41 | 40 | 43 | 0 | 0 | 0 | 19 | 38 | 48 | 47 |
| Tetrosan 3,4-D | 0 | 0 | 0 | 5 | 19 | 42 | 44 | 0 | 0 | 0 | 0 | 0 | 55 | 51 |
| Super Amide GR | 0 | 0 | 0 | 38 | 44 | 43 | 44 | 0 | 0 | 0 | 46 | 62 | 62 | 62 |

materials were ineffective in inhibiting elongation of corn roots and produced no toxicity symptoms when applied as a foliar treatment. These observations are summarized in Tables 47, 48, and 49.

Toximul R and Toximul S are anionic-nonionic blended emulsifiers. Usually, Toximul R is considered to have hydrophobic properties whereas Toximul S has hydrophilic properties. In Table 46 are summarized the responses of seed germination to these materials. Both emulsifiers effectively inhibited germination of seeds with concentrations of 0.5 percent or more. Oats were the most sensitive of the species tested. The Toximuls gave substantial reductions in elongation of corn roots when applied at concentrations of 0.05 percent or more. They also reduced the growth of young soybeans when applied as a foliar treatment. Data from these experiments are presented in Tables 47, 48, and 49.

Tetrosan 3,4-D, a N-alkyl (of variable length) dimethyl 3,4-dichlorobenzyl ammonium chloride, has bactericidal properties and Super Amide GR, a coconut fatty acid diethanolamide, is a surfactant. Both of these materials were extremely effective inhibitors of seed germination as evidenced by the data in Table 46. Results shown in Tables 47, 48, and 49 also indicated that these materials were effective in suppressing elongation of corn roots and in preventing growth of soybeans when applied as a foliar treatment, especially at high concentrations. In each of the tests involved, Tetrosan 3,4-D was more toxic than Super Amide GR.

In Tables 50, 51, 52, and 53 are presented data on the responses of seeds, roots, and leaves to another group of miscellaneous surfactants. Members of the group tested were toxic to seed germination,

Table 47. Elongation of corn roots, in centimeters, measured 3 days after treatment with 7 concentrations of selected surfactants; data are averages of measurements from 3 seedlings

| Surfactant | Concentration 0.0 | .01 | .05 | .1 | .5 | 1.0 | 5.0 |
|---|---|---|---|---|---|---|---|
| Alrodyne 6104 | 18.6 | 17.1 | 16.4 | 17.4 | 15.4 | 16.5 | 11.3 |
| Alrodyne 515 | 16.2 | 15.5 | 17.0 | 16.2 | 14.4 | 12.4 | 6.5 |
| Toximul 8 | 16.9 | 15.2 | 9.2 | 5.3 | 0.1 | 0.0 | 0.0 |
| Toximul 3 | 16.5 | 15.0 | 9.1 | 7.0 | 3.3 | 1.4 | 0.3 |
| Petrosar 3.4-D | 20.5 | 1.4 | 0.4 | 0.0 | 0.0 | 0.0 | 0.0 |
| Super Amide OR | 20.2 | 16.1 | 7.6 | 6.9 | 0.8 | 0.1 | 0.0 |

Table 48. Leaf injury ratings, 2 days after treatment, for soybeans treated with 4 concentrations of various surfactants; ratings are based on a 0-5 scale; data are means of 3 observations

| Surfactant | Concentration 1.0 | .1 | .01 | Ck |
|---|---|---|---|---|
| Alrodyne 6104 | 0 | 0 | 0 | 0 |
| Alrodyne 315 | 0 | 0 | 0 | 0 |
| Toximul R | 2 | 1 | 0 | 0 |
| Toximul S | 1 | 1 | 0 | 0 |
| Tetrosan 3,4-D | 4 | 2 | 0 | 0 |
| Super Amide GR | 3 | 1 | 0 | 0 |

Table 49. Dry weight in grams of soybean plant parts, cut off above the cotyledons, 14 days after treatment with 4 concentrations of various surfactants; each datum represents an average of 3 replications

| Surfactant | Concentration 1.0 | .1 | .01 | Ck |
|---|---|---|---|---|
| Alrodyne 6104 | .300 | .295 | .305 | .302 |
| Alrodyne 315 | .285 | .325 | .342 | .325 |
| Toximul R | .184 | .225 | .308 | .300 |
| Toximul S | .114 | .212 | .311 | .271 |
| Tetrosan 3,4-D | .000 | .079 | .167 | .295 |
| Super Amide GR | .000 | .189 | .233 | .268 |

Table 50. Total number of seeds of corn, oats, radish and giant foxtail germinating 7 days after treatment with 7 concentrations of selected surfactants; data are counts from 45 seeds, 3 replications of 15 seeds each for corn, oats, and radish; and 75 seeds, 3 replications of 25 seeds each for giant foxtail

| Surfactant | Concentration 5 | 1 | .5 | .1 | .05 | .01 | Ck | 5 | 1 | .5 | .1 | .05 | .01 | Ck |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Corn | | | | | | | Oats | | | | | | |
| Surfactant DN-65 | 0 | 0 | 1 | 24 | 35 | 45 | 45 | 0 | 0 | 0 | 0 | 1 | 37 | 43 |
| Alrowet D65 | 0 | 0 | 0 | 35 | 39 | 44 | 43 | 0 | 0 | 0 | 0 | 0 | 1 | 28 |
| Sorbit P | 0 | 0 | 9 | 45 | 45 | 43 | 45 | 0 | 0 | 0 | 0 | 10 | 36 | 37 |
| Diasyl L | 4 | 2 | 7 | 40 | 43 | 45 | 45 | 0 | 0 | 0 | 9 | 20 | 41 | 41 |
| | Radish | | | | | | | Giant Foxtail | | | | | | |
| Surfactant DN-65 | 0 | 0 | 0 | 37 | 44 | 43 | 44 | 0 | 0 | 0 | 51 | 53 | 58 | 59 |
| Alrowet D65 | 0 | 0 | 0 | 0 | 11 | 44 | 45 | 0 | 0 | 0 | 0 | 0 | 46 | 60 |
| Sorbit P | 0 | 0 | 0 | 39 | 45 | 44 | 44 | 0 | 0 | 0 | 42 | 45 | 55 | 64 |
| Diasyl L | 0 | 0 | 12 | 40 | 43 | 45 | 45 | 0 | 4 | 0 | 13 | 52 | 51 | 56 |

Table 51. Elongation of corn roots, in centimeters, measured 3 days after treatment with 7 concentrations of selected surfactants; data are averages of measurements from 3 seedlings

| Surfactant | Concentration 0.0 | .01 | .05 | .1 | .5 | 1.0 | 5.0 |
|---|---|---|---|---|---|---|---|
| Surfactant DN-65 | 17.6 | 13.7 | 2.0 | 1.9 | 1.0 | 0.0 | 0.0 |
| Surfactant WK | 15.3 | 13.6 | 0.3 | 0.1 | 0.0 | 1.0 | 0.0 |
| Sodium Xylene Sulfonate | 13.6 | 12.1 | 8.8 | 12.1 | 12.2 | 2.9 | 0.1 |
| Hyamine 2389 | 15.3 | 2.4 | 0.4 | 0.1 | 0.4 | 0.1 | 0.0 |
| Alrowet D65 | 14.5 | 9.0 | 0.4 | 0.2 | 0.0 | 0.0 | 0.0 |
| Emulsifying Agent A | 18.0 | 14.2 | 4.5 | 3.2 | 0.3 | 1.0 | 0.3 |
| Sterox SK | 15.5 | 18.0 | 6.9 | 0.2 | 0.5 | 0.0 | 0.2 |
| Sorbit P | 16.9 | 15.6 | 10.1 | 7.3 | 0.2 | 0.1 | 0.0 |
| Diasyl L | 13.5 | 14.0 | 13.5 | 3.0 | 0.0 | 0.1 | 0.0 |

Table 52. Leaf injury ratings, 2 days after treatment, for soybeans treated with 4 concentrations of various surfactants; ratings are based on a 0-5 scale; data are means of 3 observations

| Surfactant | Concentration 1.0 | .1 | .01 | Ck |
|---|---|---|---|---|
| Surfactant DN-65 | 4 | 1 | 0 | 0 |
| Surfactant WK | 4 | 2 | 0 | 0 |
| Sodium Xylene Sulfonate | 0 | 0 | 0 | 0 |
| Hyamine 2389 | 4 | 2 | 0 | 0 |
| Alrowet D65 | 4 | 1 | 0 | 0 |
| Emulsifying Agent A | 0 | 0 | 0 | 0 |
| Sterox SK | 1 | 0 | 0 | 0 |

Table 53. Dry weight in grams of soybean plant parts, cut off above the cotyledons, 14 days after treatment with 4 concentrations of various surfactants; each datum represents an average of 3 replications

| Surfactant | Concentration 1.0 | .1 | .01 | Ck |
|---|---|---|---|---|
| Surfactant DN-65 | .000 | .385 | .511 | .374 |
| Surfactant WK | .000 | .309 | .364 | .357 |
| Sodium Xylene Sulfonate | .277 | .316 | .274 | .373 |
| Hyamine 2389 | .000 | .130 | .339 | .403 |
| Alrowet D65 | .000 | .291 | .319 | .355 |
| Emulsifying Agent A | .404 | .444 | .484 | .483 |
| Sterox SK | .000 | .437 | .448 | .439 |

especially Alrowet D65, which inhibited germination of oats at concentrations as low as 0.01 percent. Response of corn roots to these surfactants indicated a high level of toxicity. Hyamine 2389 almost completely inhibited growth with concentrations as low as 0.01 percent. Foliar application with most of the members of this group resulted in hardly any growth of the first trifoliate leaves of young soybeans.

## Growth of Oats in Soil Treated with Surfactants

Dry weights of oats grown in soil treated with various surfactants at either 64, 192, or 318 gallons per acre are presented in Table 54. Each datum represents the average weight of three replications.

At least one-half of the surfactants included in this study reduced the dry matter yield when applied at 318 gallons per acre. Treatment with Alrowet D65 at concentrations as low as 64 gallons per acre resulted in almost no growth of oats. Tergitol 4 also was inhibitory, especially at the highest rate; lower rates produced moderate amounts of dry matter.

Ultrawet DS and Triton X-188 inhibited growth of oats with the two higher rates but not with the lower rate. Emulsifying Agent A, Sterox SK, and Surfactant WK all reduced growth of oats approximately 75 percent at rates of 318 gallons per acre; lower rates resulted in only slight reductions in dry matter yield. Triton X-100 and Surfactant DN-65 were fairly active at the highest rate with only nominal reductions in growth occurring at the lower rates.

Pylac, Triton B-1956, and Pluronic F-68 produced dry matter yields comparable to those of the checks.

Table 54. Dry weight in grams of oats cut off at the ground level 21 days after growth in soil treated with 3 concentrations of various surfactants; each datum represents the average of 3 replications

| Surfactant | Concentration 318 gal./acre | 192 gal./acre | 64 gal./acre |
|---|---|---|---|
| Pluronic F-68 | 3.380 | 3.372 | 3.159 |
| Triton B-1956 | 3.517 | 3.683 | 3.013 |
| Triton X-100 | 1.891 | 2.556 | 2.926 |
| Surfactant DN-65 | 1.462 | 2.943 | 2.896 |
| Emulsifying Agent A | 0.830 | 1.406 | 2.272 |
| Sterox SK | 0.714 | 2.281 | 2.738 |
| Surfactant WK | 0.451 | 2.567 | 2.879 |
| Triton X-188 | 0.429 | 0.985 | 2.302 |
| Tergitol 4 | 0.020 | 0.620 | 0.652 |
| Ultrawet DS | 0.664 | 0.817 | 2.800 |
| Alrowet D65 | 0.000 | 0.010 | 0.122 |
| Check | 3.400 | 3.400 | 3.400 |

## Growth of Soybean Plants in a Nutrient Solution which included Surfactants

The effect of surfactants on the growth of soybean plants in water culture was evaluated by growing young seedlings in sand until just before emergence of the first trifoliate leaf, and then transferring them to jars containing Hoagland's solution with 0.01, 0.1, or 1.0 percent surfactant added. Results obtained from this experiment are summarized in Table 55. Each datum represents the average dry weight of two replications.

Table 55. Dry weight in grams of soybean plant parts, cut off above the cotyledons, 21 days after growth in 3 concentrations of various surfactants; each datum represents an average of 2 replications

| Surfactant | Concentration 1.0 | .1 | .01 |
|---|---|---|---|
| Igepal Co-630 | .142 | .267 | .533 |
| Igepal Co-850 | .831 | 1.206 | 1.650 |
| Igepal Co-990 | .991 | 1.396 | 1.391 |
| Triton X-45 | .051 | .122 | .176 |
| Triton X-100 | .000 | .000 | .282 |
| Triton X-305 | .563 | .755 | 1.133 |
| Pluronic F-38 | 1.122 | 1.388 | 1.112 |
| Pluronic F-68 | 1.124 | 1.308 | 1.427 |
| Ultrawet DS | .000 | .000 | .122 |
| Sterox SK | .000 | .000 | .210 |
| Deriphat 151 | .000 | .000 | .081 |
| Emulsifying Agent A | .000 | .000 | .146 |
| Surfactant DN-65 | .075 | 1.009 | 1.357 |

Table 55. (Continued)

| Surfactant | Concentration 1.0 | .1 | .01 |
|---|---|---|---|
| Alrowet D65 | .000 | .000 | .091 |
| Carbowax 600 | 1.221 | 1.228 | 1.113 |
| Check | 1.281 | 1.281 | 1.281 |

Within the Igepal series of surfactants, Co-630 was the most effective in inhibiting the growth of soybeans at all of the concentrations tested. At 1.0 percent concentration, Co-850 and Co-990 inhibited growth of soybeans only slightly and at lower concentrations, no growth reductions were observed. These responses are illustrated in Figure 16.

The Tritons, when included in a nutrient solution, generally were inhibitory to the growth of soybeans. Triton X-100 prevented growth completely at 1.0 percent and 0.1 percent levels, with only nominal growth occurring at the 0.01 percent level.

Treatments with Triton X-45 resulted in only slight amounts of growth at 1.0 percent concentration; final yield was also severely curtailed at 0.1 percent and 0.01 percent concentration. Substantial growth of soybeans occurred when Triton X-305 was included in a final solution of 1.0 percent or 0.1 percent; treatments with 0.01 percent permitted growth comparable to untreated soybeans. These observations are illustrated in Figure 17.

Treatments which included members of the Pluronics, F-38 and F-68, and Carbowax 600, gave final dry weight yields of soybean seedlings which approximated those of non-treated checks. These responses are illustrated

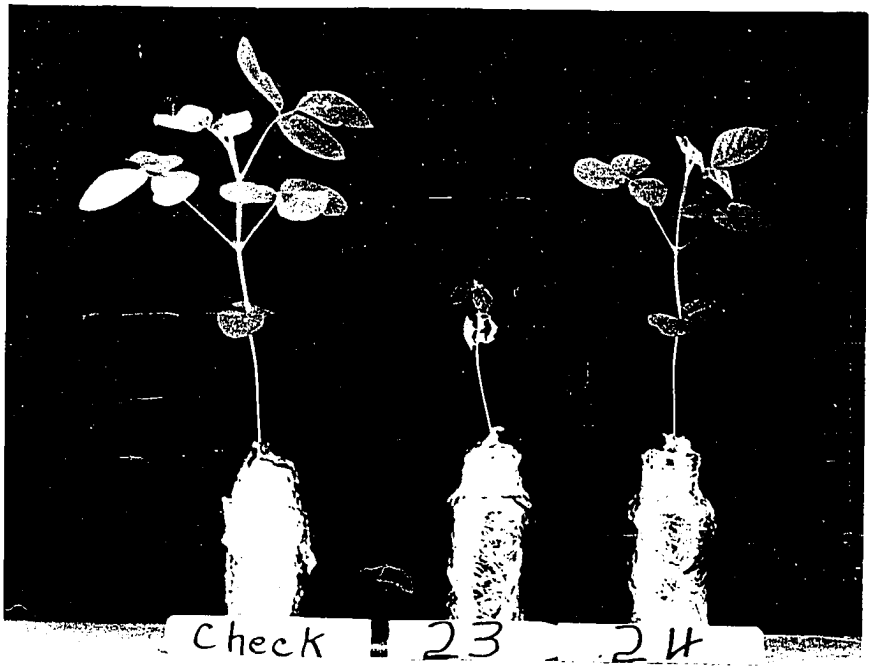



Figure 16. Soybean injury as reflected by development of young soybean plants; photo taken 14 days after growth in Hoagland's solution containing 1.0 percent (23) Igepal Co-630 and (24) Igepal Co-990

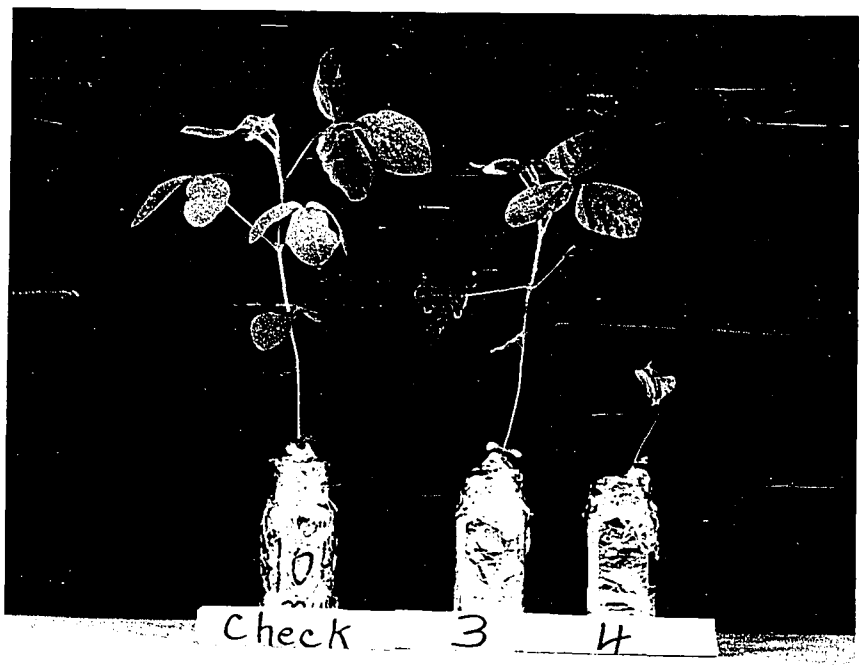



Figure 17. Soybean injury as reflected by development of young soybean plants; photo taken 14 days after growth in Hoagland's solution containing 0.1 percent (3) Triton X-305 and (4) Triton X-45

in Figure 18. Ultrawet DS, Stepanol SK, Deriphat 151, and Emulsifying Agent A completely inhibited growth of soybeans when treatments were made at concentrations of either 1.0 percent or 0.1 percent in a nutrient solution. Treatments at 0.01 percent resulted in only nominal growth of soybeans. Alrowet D65 was extremely effective in inhibiting growth of soybeans, especially at concentrations of 1.0 percent or 0.1 percent, and only slightly at 0.01 percent. Surfactant DN-65 was effective also at 1.0 percent; however, growth was comparable to checks with lower concentrations. These results are illustrated in Figure 19

## Relationship of Surface Tension to Surfactant Toxicity

In a study concerning the action of surfactants, a prime consideration is the relationship of surface tension with the surfactant response. In Table 56, the surface tension determinations are summarized for three different concentrations of a number of surfactants. There is generally a decrease in surface tension with an increase in ethylene oxide content. From previous discussion, it has been noted that there was usually a decrease in toxicity with an increase in ethylene oxide. However, a general inspection of the data shows that differences in concentration from 0.01 percent to 1.0 percent does not result in any appreciable change in surface tension. A further inspection of the response of these surfactants to plant tissues reveals that often there were marked differences in effects between 0.01, 0.1, and 1.0 percent concentrations. This pattern was evident in all of the test systems used, and especially when the surfactants were applied as a foliar treatment, where only rarely did concentrations of 0.1 percent or less have a substantial effect on young soybeans.

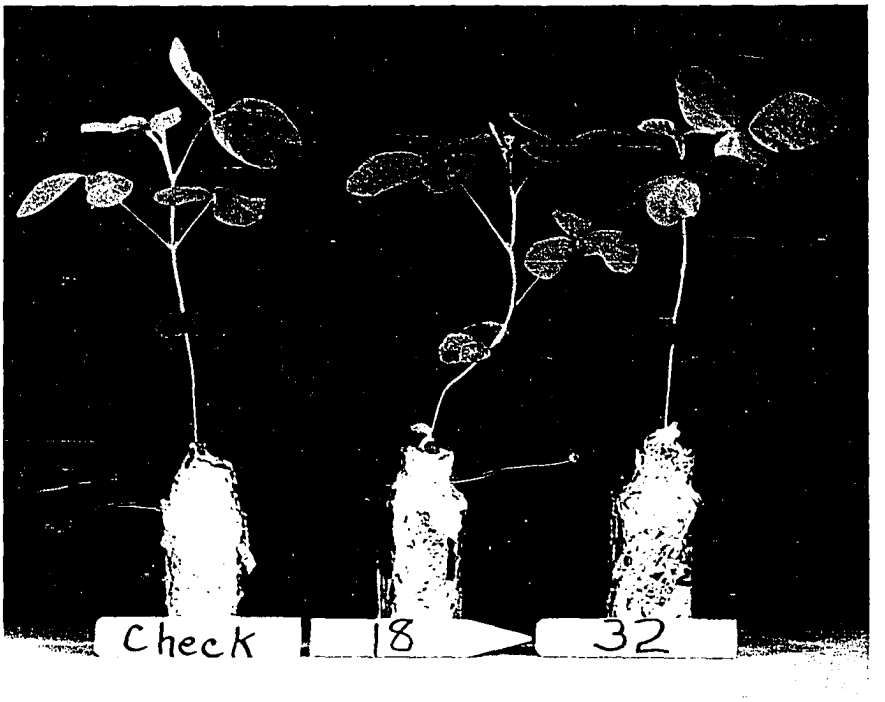



Figure 18. Soybean injury as reflected by development of young soybean plants; photo taken 14 days after growth in Hoagland's solution containing 1.0 percent (18) Pluronic F-38 and (32) Pluronic F-68

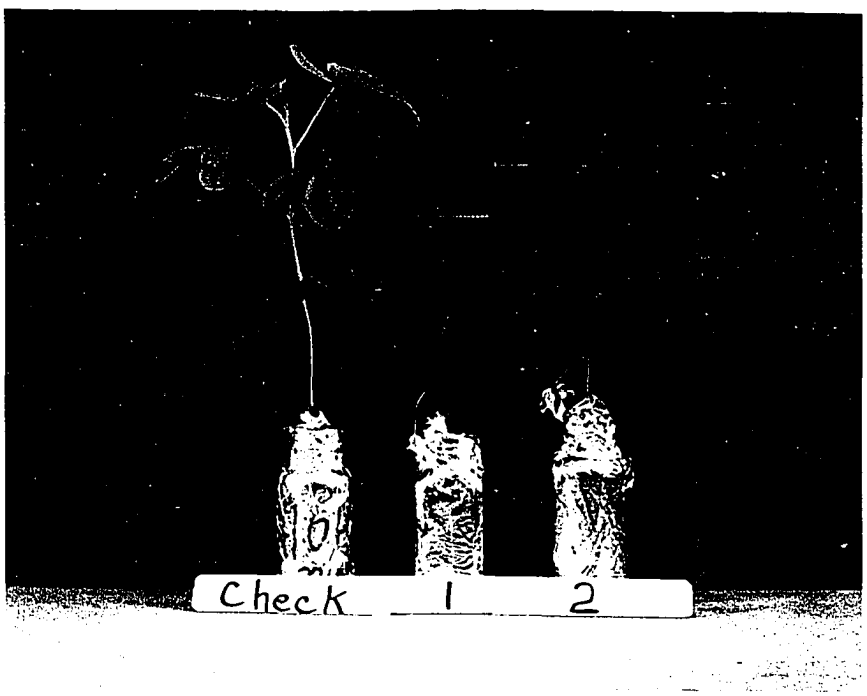



Figure 19. Soybean injury as reflected by development of young soybean plants; photo taken 14 days after growth in Hoagland's solution containing 1.0 percent (1) Alrowet D65 and (2) Surfactant DN-65

Table 56. Surface tension, in dynes/cm., of 3 concentrations of surfactant solutions at 20°C.; each datum is the average of 3 replications

| Surfactant | Concentration 1.0 | .1 | .01 |
|---|---|---|---|
| Triton X-15 | 37.7 | 38.1 | 39.5 |
| Triton X-35 | 32.5 | 32.8 | 33.0 |
| Triton X-45 | 32.1 | 33.4 | 33.2 |
| Triton X-100 | 34.0 | 34.0 | 33.0 |
| Triton X-102 | 34.0 | 34.0 | 34.0 |
| Triton X-114 | 31.0 | 32.0 | 34.0 |
| Triton X-165 | 39.0 | 38.0 | 36.0 |
| Triton X-205 | 41.0 | 39.0 | 39.0 |
| Triton X-305 | 45.0 | 42.0 | 44.0 |
| Triton N-57 | 31.7 | 33.2 | 33.0 |
| Triton N-101 | 34.6 | 35.0 | 34.7 |
| Triton N-128 | 37.0 | 37.0 | 37.1 |
| Ultrawet DS | 34.0 | 31.0 | 39.0 |
| Ultrawet 30-DS | 34.0 | 34.0 | 40.0 |
| Ultrawet K | 31.0 | 29.0 | 40.0 |
| Surfactant DN-65 | 35.8 | 33.0 | 42.0 |
| Igepal Co-630 | 35.0 | 35.0 | 35.0 |
| Igepal Co-730 | 38.0 | 39.0 | 39.0 |
| Igepal Co-890 | 47.0 | 46.0 | 50.0 |
| Igepal Co-850 | 41.0 | 43.0 | 43.0 |
| Igepal Co-970 | 49.0 | 49.0 | 50.0 |
| Igepal Co-990 | 50.0 | 46.0 | 51.0 |
| Tergitol 4 | 31.0 | 39.0 | 45.0 |
| Tergitol 7 | 29.2 | 30.6 | 38.2 |
| Tergitol 08 | 47.0 | 61.0 | 61.0 |
| Tergitol TMN | 28.0 | 29.0 | 42.0 |
| Tergitol NP-33 | 37.0 | 37.0 | 37.0 |
| Tergitol P-28 | 28.0 | 35.0 | 43.0 |
| Ethomeen 18/25 | 41.0 | 41.0 | 37.0 |
| Ethomeen 0/15 | 33.0 | 34.0 | 35.0 |
| Ethomeen T/15 | 33.0 | 31.0 | 34.0 |
| Ethomeen T/12 | 31.0 | 32.0 | 35.0 |
| Ethomeen 18/60 | 48.0 | 49.0 | 44.0 |
| Ethomeen 18/15 | 36.0 | 35.0 | 36.0 |
| Ethomid 0/15 | 31.0 | 33.0 | 32.0 |
| Ethomid HT/60 | 42.0 | 45.0 | 48.0 |

Table 56. (Continued)

| Surfactant | Concentration 1.0 | 0.1 | .01 |
|---|---|---|---|
| Ethoquad C/12 | 39.0 | 36.0 | 36.0 |
| Ethoquad 18/12 | 40.0 | 40.0 | 43.0 |
| Ethoquad 0/12 | 39.0 | 40.0 | 41.0 |
| Tetronic 304 | 50.0 | 53.0 | 57.0 |
| Tetronic 701 | 40.0 | 41.0 | 45.4 |
| Tetronic 704 | 42.0 | 44.0 | 44.0 |
| Tetronic 707 | 46.0 | 49.0 | 50.0 |
| Tetronic 908 | 45.0 | 48.0 | 53.0 |
| Pluronic F-38 | 52.0 | 52.0 | 55.0 |
| Pluronic F-68 | 50.0 | 52.0 | 52.0 |
| Pluronic F-88 | 46.0 | 49.0 | 52.0 |
| Pluronic F-98 | 43.0 | 48.0 | 53.0 |
| Pluronic F-108 | 44.0 | 47.0 | 50.7 |
| Emcol HA | 36.0 | 35.0 | 41.0 |
| Emcol HB | 35.0 | 35.0 | 47.0 |
| Emcol HC | 36.0 | 35.0 | 43.0 |
| Toximul R | 32.4 | 34.3 | 37.8 |
| Toximul S | 31.9 | 33.4 | 39.5 |
| Carbowax 300 | 55.7 | 57.8 | 57.5 |
| Carbowax 400 | 60.4 | 58.0 | 54.1 |
| Solulan 25 | 42.0 | 43.0 | 45.0 |
| Solulan 75 | 49.0 | 51.0 | 53.0 |
| Solulan 98 | 41.0 | 43.0 | 48.0 |
| Solulan C24 | 43.0 | 44.0 | 45.0 |
| Solar NP-Liquid | 34.0 | 33.0 | 33.0 |
| Solar NP | 33.0 | 40.0 | 56.0 |
| Solar NP-100 | 34.0 | 34.0 | 35.0 |
| Solar #15 | 38.0 | 39.0 | 38.0 |
| Tween 20 | 40.0 | 43.0 | 39.0 |
| Tween 40 | 43.0 | 42.0 | 48.0 |
| Tween 60 | 44.0 | 43.0 | 49.0 |
| Tween 80 | 44.0 | 45.0 | 47.0 |
| Tween 85 | 43.0 | 44.0 | 49.0 |

Table 56. (Continued)

| Surfactant | Concentration 1.0 | .1 | .01 |
|---|---|---|---|
| Emulsynt 219 | 35.4 | 34.8 | 40.2 |
| Emulsynt 224 | 36.7 | 37.3 | 40.5 |
| Emulsynt 225 | 33.2 | 35.2 | 35.3 |
| Emulsynt 610A | 37.7 | 37.8 | 41.4 |
| Nonisol 100 | 36.3 | 36.3 | 38.1 |
| Nonisol 200 | 38.9 | 38.2 | 39.7 |
| Nonisol 110 | 39.9 | 41.2 | 38.4 |
| Nonisol 210 | 34.0 | 36.7 | 44.9 |
| Nonisol 250 | 40.5 | 40.5 | 43.0 |
| Nonisol 300 | 32.9 | 36.5 | 39.3 |
| Alrosol | 31.1 | 30.8 | 29.4 |
| Alrosol B | 31.5 | 31.2 | 31.3 |
| Alrosol C | 31.6 | 30.2 | 53.8 |
| Alrosol O | 32.3 | 32.4 | 34.1 |
| Alrosperse DC | 33.5 | 34.4 | 30.2 |
| Alrosperse 100 | 30.6 | 30.0 | 31.2 |
| Miranol CM | 34.0 | 29.0 | 30.0 |
| Miranol HM | 32.0 | 27.0 | 27.0 |
| Deriphat 151 | 31.7 | 31.1 | 33.8 |
| Deriphat 154 | 41.5 | 40.0 | 38.2 |
| Deriphat 160 | 38.5 | 39.5 | 55.2 |
| Deriphat 151C | 32.0 | 31.3 | 31.8 |
| Deriphat 170C | 32.2 | 32.6 | 31.1 |
| Alkanol OA | 33.2 | 31.8 | 32.7 |
| Alkanol OJ | 34.7 | 34.8 | 36.6 |
| Alkanol OP | 39.6 | 40.9 | 39.6 |
| Alkanol HC | 42.3 | 43.5 | 42.4 |
| Alkanol HCS | 42.0 | 42.4 | 44.2 |
| Super Amide GR | 32.2 | 33.6 | 35.8 |
| Tetrosan 3,4-D | 39.8 | 38.0 | 41.9 |
| Surfactant WK | 29.0 | 29.0 | 37.0 |
| Emulsifying Agent A | 33.0 | 35.0 | 43.0 |

Table 56. (Continued)

| Surfactant | Concentration 1.0 | .1 | .01 |
|---|---|---|---|
| Sterox SK | 32.0 | 32.0 | 32.0 |
| Sodium Xylene Sulfonate | 47.0 | 57.0 | 59.0 |
| Solefonate 98K | 33.0 | 34.0 | 42.0 |
| Solefonate 104 | 34.0 | 35.0 | 41.0 |
| Sulfanole FAS | 31.0 | 35.0 | 43.0 |
| Sulfanole KA | 30.0 | 33.0 | 46.0 |

## Effect of Some Selected Surfactants on Permeability of Beet Tissue Cells

The effects of surfactants on the permeability of beet tissue membrane were studied using slices of beet tissue approximately 1.0 mm. in diameter. These sections were washed in distilled water and five sections were placed in 5 ml. of either 0.0, 0.01, 0.05, 0.1, 0.5, 1.0, or 5.0 percent surfactant solution contained in a 10 ml. beaker. After the specified period of time, the solution was poured into matched cuvettes and the percent transmission determined with a Bausch & Lomb Spectronic 20 colorimeter at 538mμ. A decrease in percent transmission indicates an increase in the permeability of the cells of beet root tissue. Percent transmission of light through the extract of beets treated with various surfactants at 7 concentrations is presented in Table 57. Each datum represents the average of 3 replications.

Table 57. Percent transmission of surfactant-beet extract 27 minutes after immersion of washed beet discs in 5 ml. of 7 different concentrations of selected surfactants

| Surfactant | Concentration 5 | 1 | .5 | .1 | .05 | .01 | Ck |
|---|---|---|---|---|---|---|---|
| Triton X-100 | 44 | 51 | 64 | 73 | 82 | 93 | 93 |
| Triton X-102 | 77 | 80 | 88 | 84 | 88 | 90 | 93 |
| Triton X-114 | 62 | 81 | 89 | 90 | 91 | 90 | 92 |
| Triton X-165 | 92 | 93 | 93 | 93 | 95 | 96 | 96 |
| Triton X-205 | 88 | 87 | 91 | 90 | 92 | 93 | 92 |
| Triton X-305 | 94 | 95 | 96 | 96 | 95 | 97 | 96 |
| Triton N-101 | 50 | 54 | 55 | 74 | 79 | 88 | 94 |
| Triton N-128 | 88 | 89 | 90 | 91 | 94 | 96 | 96 |
| Tergitol 4 | 4 | 2 | 3 | 9 | 43 | 94 | 94 |
| Tergitol P-28 | 1 | 1 | 1 | 2 | 6 | 72 | 92 |
| Tergitol TMN | 13 | 14 | 21 | 49 | 82 | 94 | 94 |
| Tergitol NP-33 | 81 | 88 | 87 | 86 | 86 | 90 | 96 |
| Tergitol 08 | 21 | 93 | 90 | 91 | 91 | 92 | 93 |
| Tergitol 7 | 4 | 5 | 7 | 6 | 6 | 24 | 94 |
| Ethoquad C/12 | 0 | 0 | 0 | 6 | 12 | 73 | 96 |
| Ethoquad 18/12 | 10 | 35 | 34 | 69 | 82 | 85 | 95 |
| Ethoquad 0/12 | 9 | 18 | 29 | 54 | 54 | 63 | 93 |
| Ethomeen 18/25 | 42 | 52 | 55 | 57 | 76 | 92 | 94 |
| Ethomeen 18/60 | 96 | 94 | 95 | 95 | 96 | 100 | 96 |
| Ethomid HT/60 | 53 | 67 | 81 | 94 | 92 | 95 | 97 |
| Alrosol | 38 | 23 | 34 | 35 | 65 | 86 | 92 |
| Alrosol C | 4 | 4 | 8 | 91 | 95 | 97 | 97 |
| Alrosol B | 54 | 66 | 67 | 70 | 84 | 93 | 95 |

Table 57. (Continued)

| Surfactant | Concentration 5 | 1 | .5 | .1 | .05 | .01 | Ck |
|---|---|---|---|---|---|---|---|
| Deriphat 151C | 17 | 22 | 23 | 49 | 66 | 88 | 95 |
| Deriphat 151 | | 21 | 22 | 51 | 61 | 90 | 93 |
| Deriphat 170C | 84 | 86 | 87 | 89 | 89 | 91 | 94 |
| Deriphat 160 | 76 | 81 | 79 | 86 | 88 | 91 | 95 |
| Deriphat 160C | 73 | 74 | 81 | 81 | 83 | 92 | 93 |
| Deriphat 154 | 72 | 74 | 82 | 81 | 84 | 91 | 96 |
| Miranol CM | 85 | 54 | 25 | 35 | 55 | 93 | 99 |
| Miranol HM | 82 | 57 | 44 | 41 | 53 | 90 | 97 |
| Ultrawet DS | 7 | 13 | 14 | 17 | 39 | 93 | 96 |
| Ultrawet 30-DS | 6 | 16 | 15 | 15 | 38 | 96 | 96 |
| Ultrawet K | 5 | 8 | 10 | 15 | 32 | 95 | 97 |
| Solefonate 98K | 6 | 14 | 20 | 34 | 39 | 91 | 95 |
| Solefonate 104 | 3 | 12 | 18 | 18 | 34 | 90 | 93 |
| Sulfanole KA | 12 | 5 | 6 | 14 | 26 | 87 | 88 |
| Sulfanole FAF | 3 | 11 | 44 | 74 | 82 | 91 | 95 |
| Nonisol 100 | 29 | 57 | 87 | 91 | 91 | 90 | 88 |
| Nonisol 250 | 78 | 81 | 84 | 87 | 90 | 86 | 88 |
| Cetyl Pyridinum chloride | 15 | 30 | 36 | 64 | 66 | 71 | 83 |
| Cetol | 5 | 13 | 25 | 34 | 48 | 63 | 92 |
| Sorbit P | 19 | 15 | 26 | 81 | 94 | 96 | 96 |

Table 57. (Continued)

| Surfactant | Concentration 5 | 1 | .5 | .1 | .05 | .01 | Ck |
|---|---|---|---|---|---|---|---|
| Sterox SK | 10 | 25 | 60 | 72 | 86 | 98 | 96 |
| Surfactant WK | 11 | 10 | 18 | 53 | 82 | 94 | 97 |
| Emulsifying Agent A | 15 | 22 | 23 | 54 | 90 | 96 | 94 |
| Toximul S | 9 | 24 | 39 | 42 | 74 | 95 | 95 |
| Tetrosan 3,4-D | 3 | 7 | 14 | 10 | 16 | 64 | 90 |
| Diasyl L | | | 1 | 3 | 42 | 87 | 95 |
| Hyamine 2389 | 2 | 7 | 4 | 6 | 4 | 10 | 90 |
| Alrowet D65 | 2 | 11 | 4 | 7 | 10 | 96 | 98 |
| Tetronic 304 | 97 | 97 | 97 | 95 | 95 | 93 | 95 |
| Tetronic 704 | 88 | 89 | 89 | 86 | 86 | 86 | 92 |
| Tetronic 707 | 93 | 92 | 88 | 92 | 97 | 87 | 90 |
| Tetronic 702 | 88 | 89 | 89 | 86 | 86 | 86 | 93 |
| Tetronic 908 | 93 | 88 | 92 | 91 | 91 | 91 | 96 |
| Pluronic F-38 | 98 | 97 | 98 | 97 | 97 | 98 | 93 |
| Pluronic F-68 | 93 | 92 | 93 | 95 | 95 | 94 | 92 |
| Pluronic F-88 | 84 | 89 | 90 | 91 | 92 | 92 | 93 |
| Pluronic F-98 | 94 | 95 | 95 | 95 | 96 | 95 | 92 |
| Pluronic F-108 | 90 | 90 | 90 | 91 | 91 | 91 | 94 |

Table 57. (Continued)

| Surfactant | Concentration 5 | 1 | .5 | .1 | .05 | .01 | Ck |
|---|---|---|---|---|---|---|---|
| Solulan 25 | 91 | 92 | 92 | 92 | 94 | 92 | 90 |
| Solulan 75 | 91 | 90 | 90 | 92 | 89 | 91 | 91 |
| Solulan 98 | 80 | 81 | 82 | 84 | 84 | 83 | 92 |
| Solulan C24 | 90 | 92 | 93 | 91 | 93 | 93 | 93 |
| Igepal Co-630 | 89 | 91 | 91 | 90 | 91 | 90 | 95 |
| Igepal Co-730 | 89 | 89 | 88 | 88 | 90 | 90 | 93 |
| Igepal Co-890 | 98 | 99 | 99 | 99 | 99 | 99 | 99 |
| Igepal Co-850 | 82 | 84 | 86 | 88 | 89 | 91 | 93 |
| Igepal Co-970 | 89 | 87 | 88 | 89 | 91 | 90 | 92 |
| Igepal Co-990 | 89 | 89 | 90 | 91 | 91 | 90 | 92 |
| Carbowax 300 | 86 | 88 | 90 | 89 | 90 | 91 | 94 |
| Carbowax 400 | 81 | 78 | 89 | 85 | 77 | 87 | 82 |
| Carbowax 600 | 93 | 92 | 93 | 89 | 93 | 91 | 92 |
| Tween 20 | 95 | 93 | 92 | 92 | 94 | 94 | 90 |
| Tween 40 | 89 | 89 | 92 | 91 | 92 | 91 | 91 |
| Tween 60 | 89 | 89 | 91 | 93 | 94 | 92 | 93 |
| Tween 80 | 91 | 90 | 90 | 92 | 94 | 93 | 96 |
| Sodium Xylene Sulfate | 73 | 90 | 90 | 92 | 93 | 91 | 96 |

Table 57. (Continued)

| Surfactant | Concentration 5 | 1 | .5 | .1 | .05 | .01 | Ck |
|---|---|---|---|---|---|---|---|
| Alkanol OJ | 97 | 94 | 96 | 95 | 95 | 97 | 97 |
| Alkanol HC | 98 | 98 | 99 | 99 | 98 | 97 | 96 |
| Alkanol OP | 95 | 97 | 98 | 97 | 99 | 98 | 96 |
| Alkanol HCS | 94 | 92 | 92 | 96 | 94 | 97 | 91 |
| Emulsynt 219 | 56 | 91 | 91 | 95 | 94 | 94 | 95 |
| Emulsynt 224 | 83 | 80 | 81 | 85 | 87 | 86 | 96 |
| Emulsynt 610A | 89 | 91 | 90 | 92 | 96 | 94 | 96 |

Within the Triton series of surfactants, X-100 was most effective in increasing the permeability of the cells of beet root tissue; substantial increases occurred at concentrations of 0.1 percent and higher. At 1.0 and 5.0 percent concentrations, both X-114 and X-102 increased the permeability of beet tissue, but lower concentrations had no appreciable effect on permeability. Tritons X-165, X-205, X-305, and N-128 did not increase permeability of beet tissue at the concentrations tested, as measured by loss of pigment from cells. Triton N-101, a member of the series containing a nonyl phenol hydrophobe, increased the permeability of beet tissue substantially at concentrations as low as 0.1 percent.

Tergitol 7 increased the permeability of beet tissue membrane at concentrations as low as 0.01 percent. Tergitol P-28 was effective at concentrations of 0.05 percent or greater; Tergitol 4 gave results comparable to Tergitol P-28. The permeability of beet tissue membrane was increased considerably at concentrations greater than 0.5 percent of Tergitol TMN; little response was observed at concentrations greater than 0.05 percent. Tergitol 08, although effective at 5.0 percent, had little effect on permeability of beet tissue cells at concentrations of 1.0 percent or lower. Tergitol NP-33 had little effect on permeability of beet tissue,

Of the two Ethomeen surfactants included in this study, Ethomeen 18/60 was ineffective in modifying beet tissue membrane permeability. Ethomeen 18/25 was effective at concentrations as low as 0.05 percent. The Ethoquad surfactants, which contain the same amount of ethylene oxide but differ in the alkyl radical, presented a range of effects on permeability of beet tissue membranes. Ethoquad C/12 was, by far, the most potent in modifying membranes with some response noted at concentrations of 0.01 percent.

Ethoquad 18/12 was considerably less effective than the C/12; substantial increases in permeability occurred only at concentrations greater than 0.05 percent. These results are illustrated in Figure 20 and supported by an analysis of variance in Table 58.

Ethomid HT/60 increased the permeability of beet tissue membranes at either 1.0 or 5.0 percent concentration; lower concentrations had little effect.

At concentrations of 0.5 percent or greater, Alrosol C was extremely effective in modifying the differentially permeable properties of beet tissue membrane. Lower concentrations of Alrosol C were ineffective. Alrosol B was only moderately effective at concentrations greater than 0.05 percent. Alrosol was more effective than Alrosol B but less effective than Alrosol C.

The Deriphats, which are amphoteric surfactants, had different effects on cells of beet tissue. Deriphat 151 and 151C were both quite effective at concentrations below 0.05 percent. Deriphat 170C and Deriphat 160 were only slightly effective at either 1.0 or 5.0 percent concentration; lower concentrations did not increase permeability substantially. At concentrations greater than 0.01 percent, Deriphat 160C and Deriphat 154 were moderately effective in increasing the permeability of beet tissue.

Increases in permeability of beet tissue resulted with both Miranol CM and HM at concentrations of 0.05 percent and higher. At 1.0 and 5.0 percent concentrations there was a greater percent transmission of light than at 0.1 percent concentration which may have been due to some interaction of the plant pigment with the surfactant.

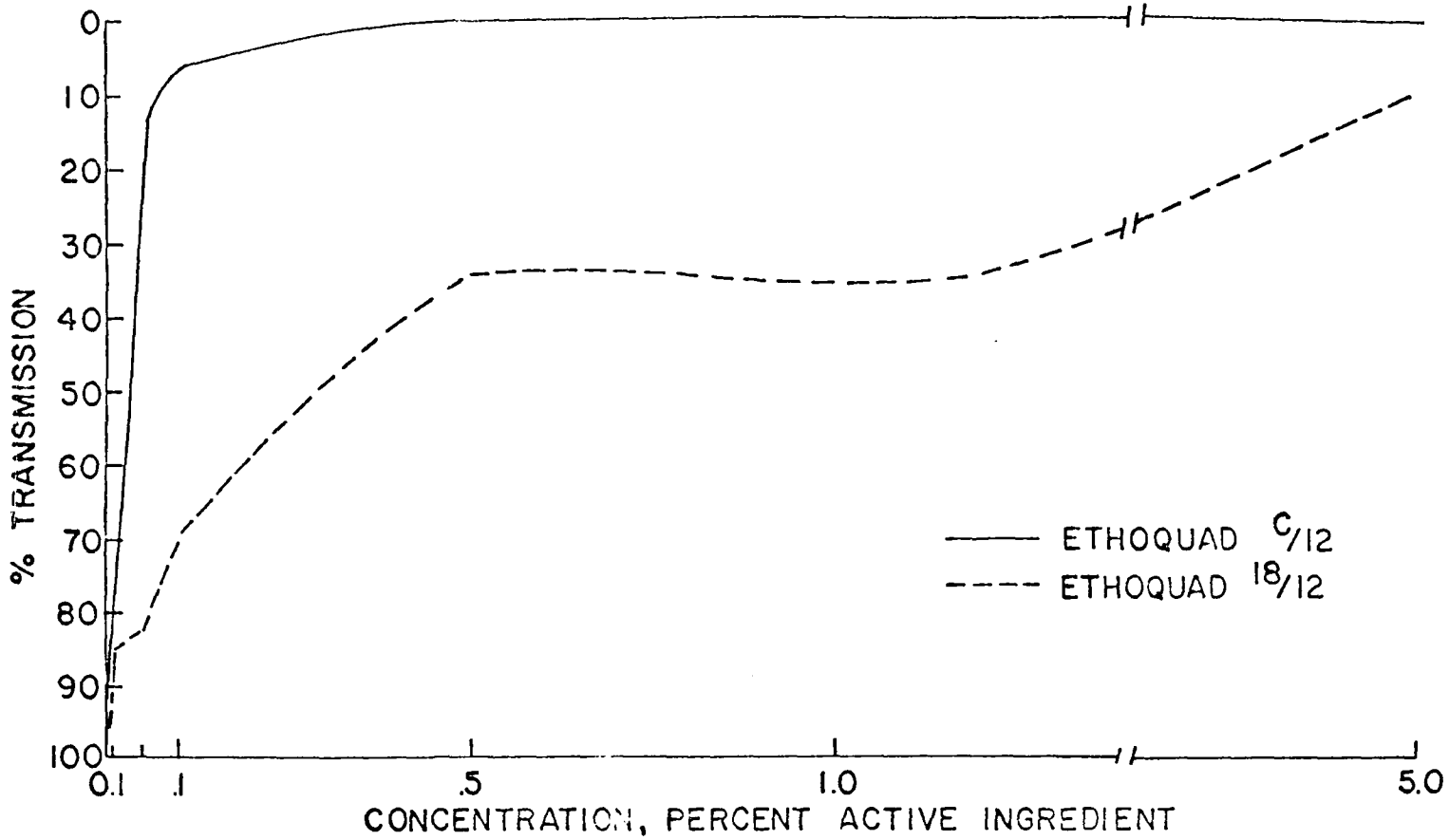



Figure 20. Percent transmission of surfactant-beet extract 27 minutes after immersion of washed beet discs in 5.0 ml. of 7 different concentrations of Ethoquad C/12 and Ethoquad 18/12

Table 58. Analysis of variance for beet permeability data

| Source of variation | df | Sum of squares | Mean square | F values |
|---|---|---|---|---|
| Surfactant | 1 | 10,848.21 | 10,848.21 | 1,280.78** |
| Concentration | 6 | 41,094.95 | 6,849.15 | 808.63** |
| Surfactant x Concentration | 6 | 6,591.62 | 1,098.60 | 129.70** |
| Error | 28 | 237.34 | 8.47 | |

**Denotes significant differences at P = 0.01.

Two Sulfanole surfactants, Sulfanole KA and FAF, were extremely effective in destroying the differentially permeable properties of beet tissue membranes. Sulfanole KA was active at concentrations as low as 0.05 percent; Sulfanole FAF only at concentrations of 0.5 percent or greater.

Members of the Ultrawet series of surfactants increased substantially the permeability of beet tissue at concentrations as low as 0.05 percent. The three members of the series tested all gave comparable results.

Sole-Fonate 98K and Sole-Fonate 104, dodecylbenzene sulfonic acid, and the sodium salt of dodecylbenzene sulfonic acid, increased the permeability of beet tissue membranes at concentrations as low as 0.05 percent. Both materials gave similar responses.

A group of miscellaneous surfactants, representing a number of chemical structures, had several different effects on the permeability of cell membranes in beet root tissue. Treatments with the higher concentrations were quite effective; however, only a few surfactants increased the loss of red pigment from beet tissue with treatments at the lower concentrations.

A notable exception was Hyamine 2389, which was extremely active at concentrations as low as 0.01 percent.

Several of the families of surfactants included in this investigation had no observable effect on permeability of beet cell membranes. These families represent a number of different chemical types of surfactants.

In Table 59 are presented percent transmission of light at 3, 9, 18, and 27 minutes through beet tissue extract, when treated with various surfactants at 7 different concentrations. Of the surfactants which did increase the permeability of beet tissue membranes, the rate of loss of beet exudate was most rapid during the first 9 minutes. Usually the rate of loss of beet extract was not substantial after 9 minutes. These effects are illustrated in Figures 21, 22, and 23.

## Electron Microscope Observations

Soybean tissue, selected from the first trifoliate leaf when the leaf was very young, was observed with the electron microscope after treatment with selected surfactants at different concentrations. Some experiments involved a uniform concentration of surfactants with length of exposure as the variable.

Cytoplasmic organelles found in young untreated soybean tissue were characteristic of those in meristematic tissue of most higher plants. Note in Figures 24 and 25 the nucleus, nucleous, mitochondria, Golgi complex, endoplasmic reticulum, ribosomes, microtubules, various membrane systems, and chloroplasts with included starch granules.

Treatments of young soybean leaf tissue with a 1.0 percent concentration of Tergitol P-28 for 5 minutes resulted in partial loss of the

Table 59. Percent transmission of surfactant-beet extract at 3, 9, 18 and 27 minutes after immersion of washed beet discs in 5 ml. of 7 different concentrations of selected surfactants

| Surfactant | Concentration | Time in minutes 3 | 9 | 18 | 27 |
|---|---|---|---|---|---|
| Tergitol 4 | 0.0 | 95 | 96 | 95 | 94 |
| | 0.01 | 97 | 93 | 93 | 90 |
| | 0.05 | 97 | 95 | 91 | 68 |
| | 0.1 | 75 | 41 | 28 | 20 |
| | 0.5 | 53 | 11 | 4 | 2 |
| | 1.0 | 53 | 21 | 6 | 5 |
| | 5.0 | 49 | 16 | 5 | 3 |
| Tergitol TMN | 0.0 | 97 | 96 | 94 | 94 |
| | 0.01 | 96 | 96 | 94 | 94 |
| | 0.05 | 96 | 96 | 93 | 82 |
| | 0.1 | 97 | 90 | 75 | 49 |
| | 0.5 | 96 | 61 | 32 | 21 |
| | 1.0 | 92 | 48 | 20 | 11 |
| | 5.0 | 88 | 75 | 25 | 13 |
| Tergitol NP-33 | 0.0 | 96 | 96 | 95 | 94 |
| | 0.01 | 97 | 97 | 95 | 95 |
| | 0.05 | 97 | 95 | 92 | 90 |
| | 0.1 | 98 | 94 | 96 | 93 |
| | 0.5 | 98 | 96 | 95 | 95 |
| | 1.0 | 99 | 93 | 91 | 90 |
| | 5.0 | 97 | 95 | 94 | 90 |
| Aerowet D65 | 0.0 | 96 | 93 | 92 | 91 |
| | 0.01 | 96 | 94 | 90 | 88 |
| | 0.05 | 93 | 67 | 44 | 29 |
| | 0.1 | 87 | 40 | 21 | 12 |
| | 0.5 | 65 | 27 | 17 | 12 |
| | 1.0 | 63 | 16 | 6 | 3 |
| | 5.0 | 46 | 9 | 3 | 1 |
| Igepal 990 | 0.0 | 94 | 91 | 91 | 89 |
| | 0.01 | 96 | 92 | 91 | 90 |
| | 0.05 | 96 | 91 | 93 | 92 |
| | 0.1 | 95 | 90 | 89 | 89 |
| | 0.5 | 97 | 94 | 90 | 89 |
| | 1.0 | 97 | 93 | 91 | 90 |
| | 5.0 | 97 | 93 | 90 | 90 |

Table 59. (Continued)

| Surfactant | Concentration | Time in minutes 3 | 9 | 18 | 27 |
|---|---|---|---|---|---|
| Pluronic F-88 | 0.0 | 97 | 94 | 92 | 90 |
| | 0.01 | 98 | 96 | 94 | 93 |
| | 0.05 | 98 | 95 | 92 | 91 |
| | 0.1 | 98 | 95 | 94 | 93 |
| | 0.5 | 97 | 95 | 92 | 91 |
| | 1.0 | 97 | 95 | 93 | 92 |
| | 5.0 | 97 | 96 | 94 | 94 |

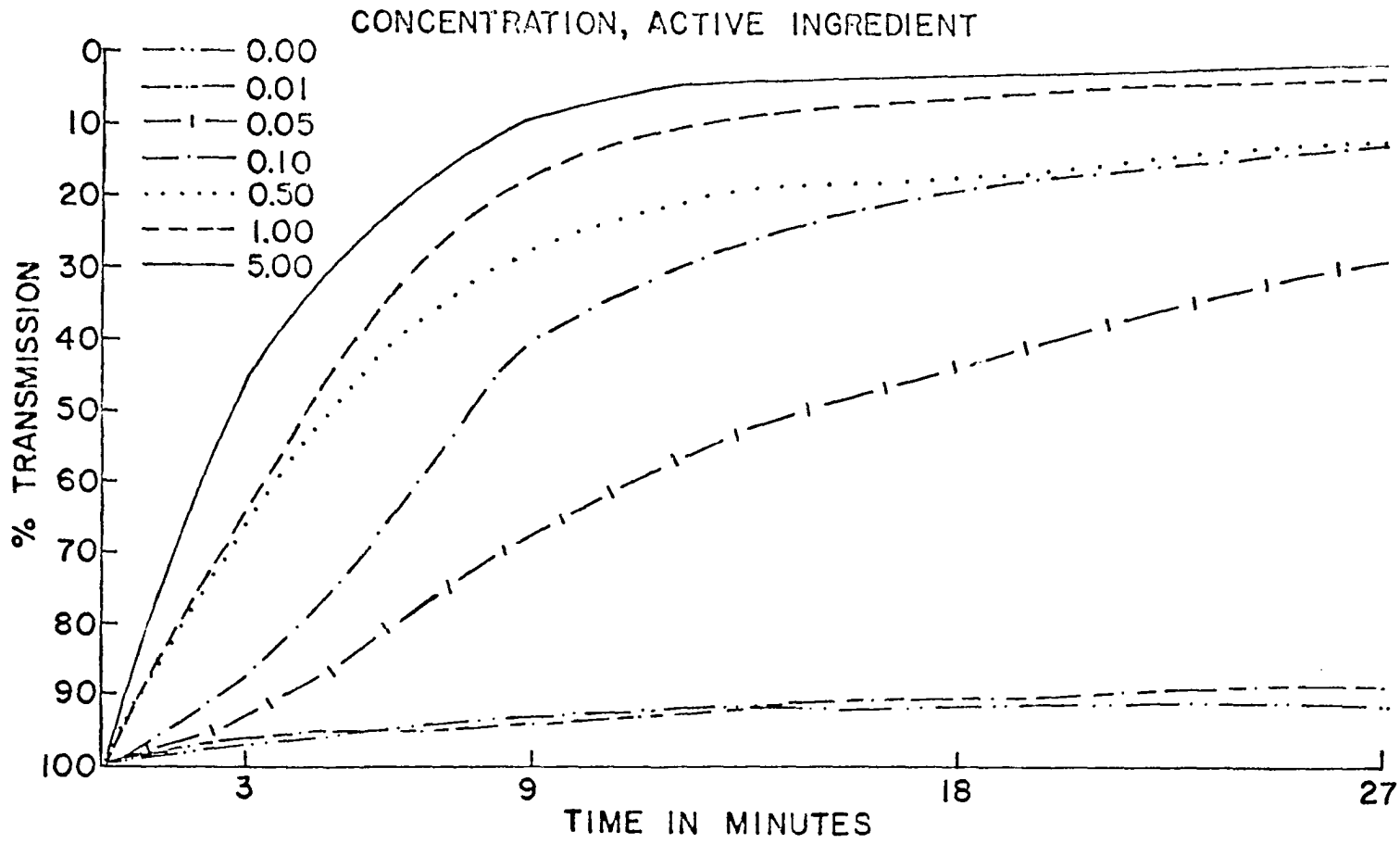



Figure 21. Percent transmission of surfactant-beet extract at 3, 9, 18, and 27 minutes after immersion of washed beet discs in 5.0 ml. of 7 different concentrations of Alrowet D05

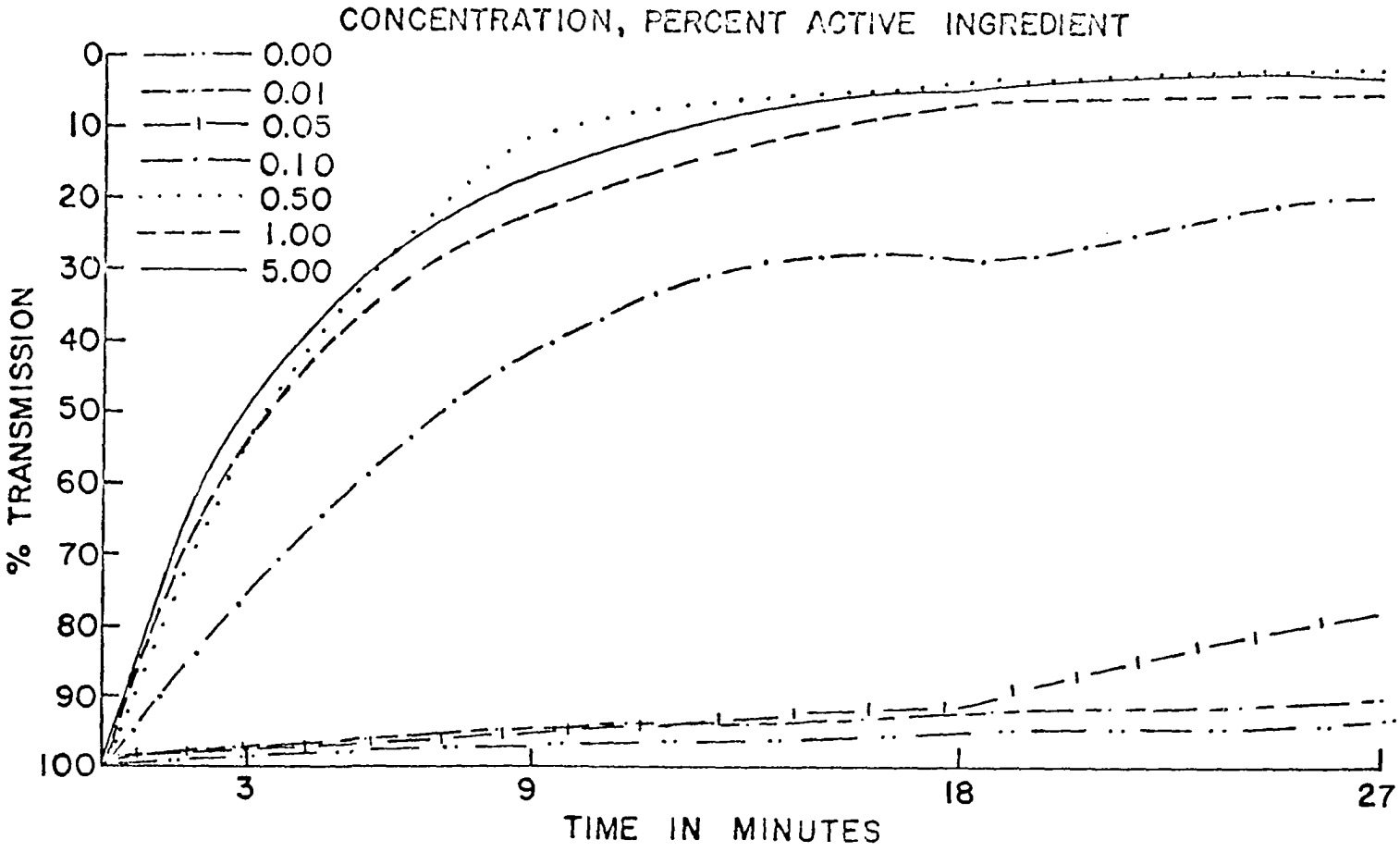



Figure 22. Percent transmission of surfactant-beet extract at 3, 9, 18, and 27 minutes after immersion of washed beet discs in 5.0 ml. of 7 different concentrations of Tergitol 4

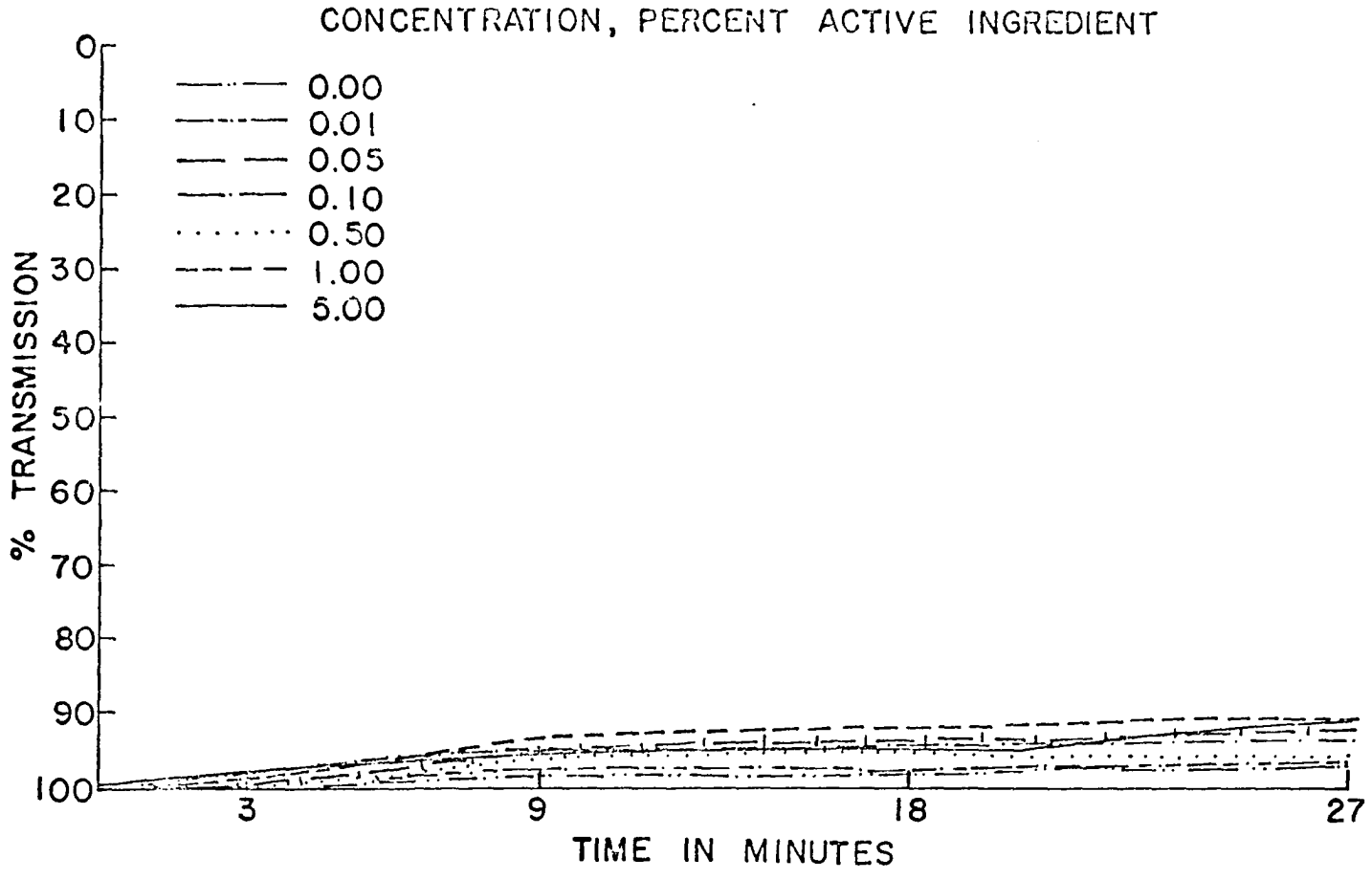



Figure 23. Percent transmission of surfactant-beet extract at 3, 9, 18, and 27 minutes after immersion of washed beet discs in 5.0 ml. of 7 different concentrations of Tergitol NP-33

Figure 24. Portion of a cell of soybean leaf; note the cell wall (CW), nucleus (N), nucleolus (NO), endoplasmic reticulum (ER), ribosomes (R), mitochondria (M), chloroplast (C), starch granules (SG); glutaraldehyde fixation, post-fixed in $OsO_4$ and stained with lead citrate. Approximately X51,000

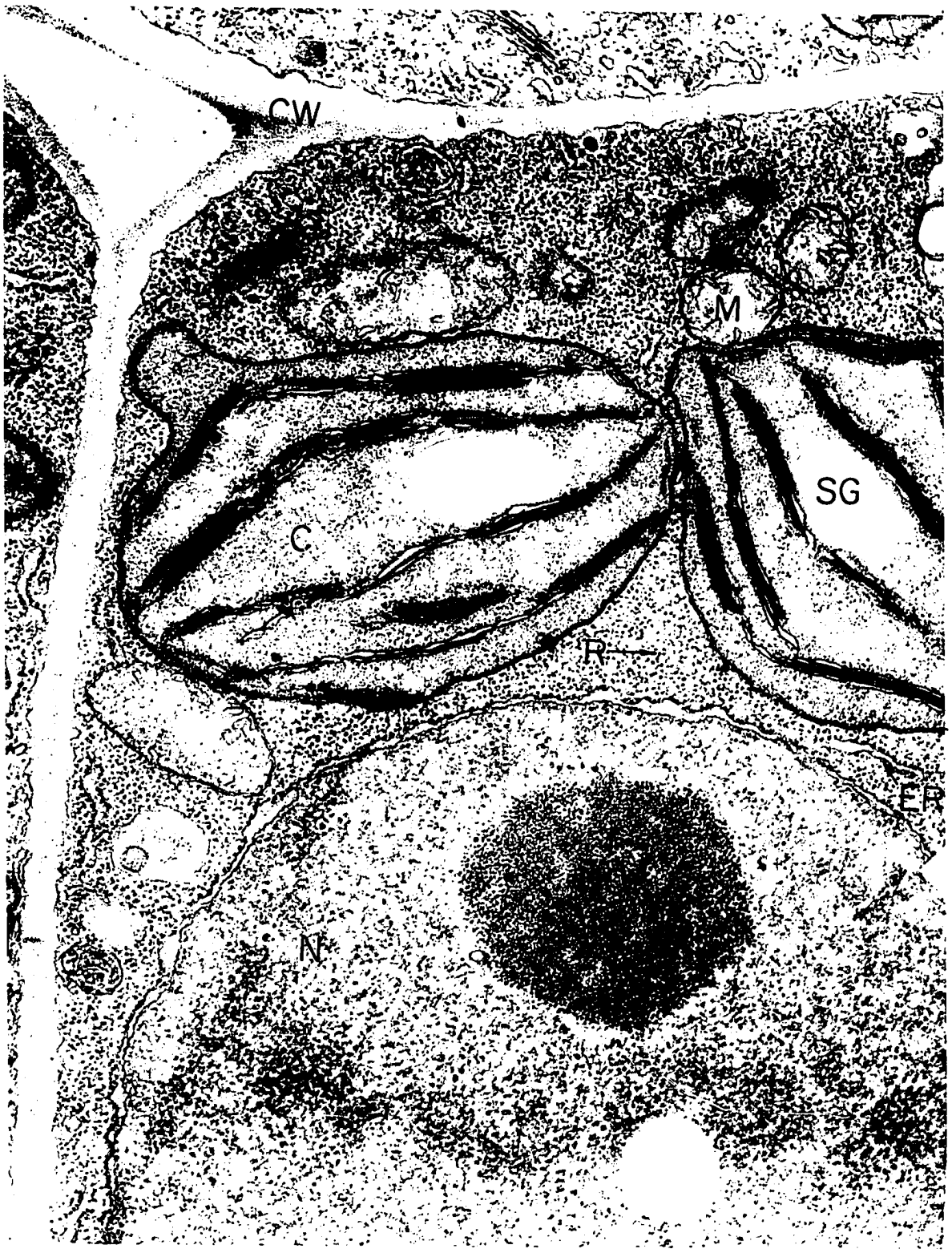

CW
M
SG
C
R
ER
N

Figure 25. Portion of a cell of a young soybean leaf; note the cell wall (CW), chloroplast (C), mitochondria (M), endoplasmic reticulum (ER), ribosomes (R), Golgi complex (G), and microtubules (MT); glutaraldehyde fixation, post-fixed in $OsO_4$ and stained with lead citrate. Approximately X72,000


M
R
M
CW
PM

internal structure of the chloroplast; however, the two unit membranes surrounding the chloroplast appear intact (Figure 26). Treatments with the same concentrations for 20 to 40 minutes resulted in still further deterioration of cellular organelles (Figures 27 and 28).

No detectable disruption of cellular organization was observed in soybean tissue treated with a 0.01 percent concentration of Tergitol P-28 for 40 minutes (Figure 29). However, treatments with 0.1 and 1.0 percent concentrations resulted in a progressive loss of cellular structure (Figures 30 and 31).

To study the effect of different ionogenic-type surfactants on young soybean tissue, one experiment included a cationic, an ionic, a nonionic, and an amphoteric-type surfactant. Ethomeen T/15, a cationic, Ultrawet 30-DS, an anionic, and the biodegradable Surfactant DN-65, a nonionic, and Deriphat 151, an amphoteric, were used to represent the four ionogenic classes.

Treatment with 1.0 percent concentrations of each of these surfactants resulted in tissue with some form of structural disorganization (Figures 32, 33, 34, 35, and 36).

From earlier results in this investigation, it was observed that a number of surfactants had no apparent effect on growth and development of plants. Two such surfactants, Pluronic F-68, a compound formed by sequential addition of propylene and ethylene oxide to propylene glycol, and Igepal Co-990, a nonyl phenoxypoly(ethyleneoxy) ethanol, were used to treat tissue from young soybean leaves. No apparent loss of structure of cellular organelles (Figures 37, 38, and 39) was observed with the electron

Figure 26. Portion of two cells from tissue of a young soybean leaf treated with a 1.0 percent concentration of Tergitol P-28 for 5 minutes; note the cell wall (CW) and absence of a well-defined plasma membrane; also, the chloroplast (C) which has already undergone significant structure changes; the two unit-enveloping membranes are essentially intact; glutaraldehyde fixation, post-fixed in $OsO_4$ and stained with lead citrate. Approximately X37,000


CW

Figure 27. Portion of three cells from tissue of a young soybean leaf treated with a 1.0 percent concentration of Tergitol P-28 for 20 minutes; note the absence of a limiting plasma membrane; also, partial disruption of enveloping membranes around chloroplast; glutaraldehyde fixation, post-fixed in $OsO_4$ and stained with lead citrate. Approximately X37,000

Figure 28. Portion of a cell from young soybean leaf tissue treated with a 1.0 percent concentration of Tergitol P-28 for 40 minutes; note still further deterioration of cellular structure; glutaraldehyde fixation, post-fixed in $OsO_4$ and stained with lead citrate. Approximately X51,000

Figure 29. Portion of a cell from young soybean leaf tissue treated with a 0.01 percent concentration of Tergitol P-28 for 40 minutes; note the apparently normal chloroplast; glutaraldehyde fixation, post-fixed in $OsO_4$ and stained with lead citrate. Approximately X72,000

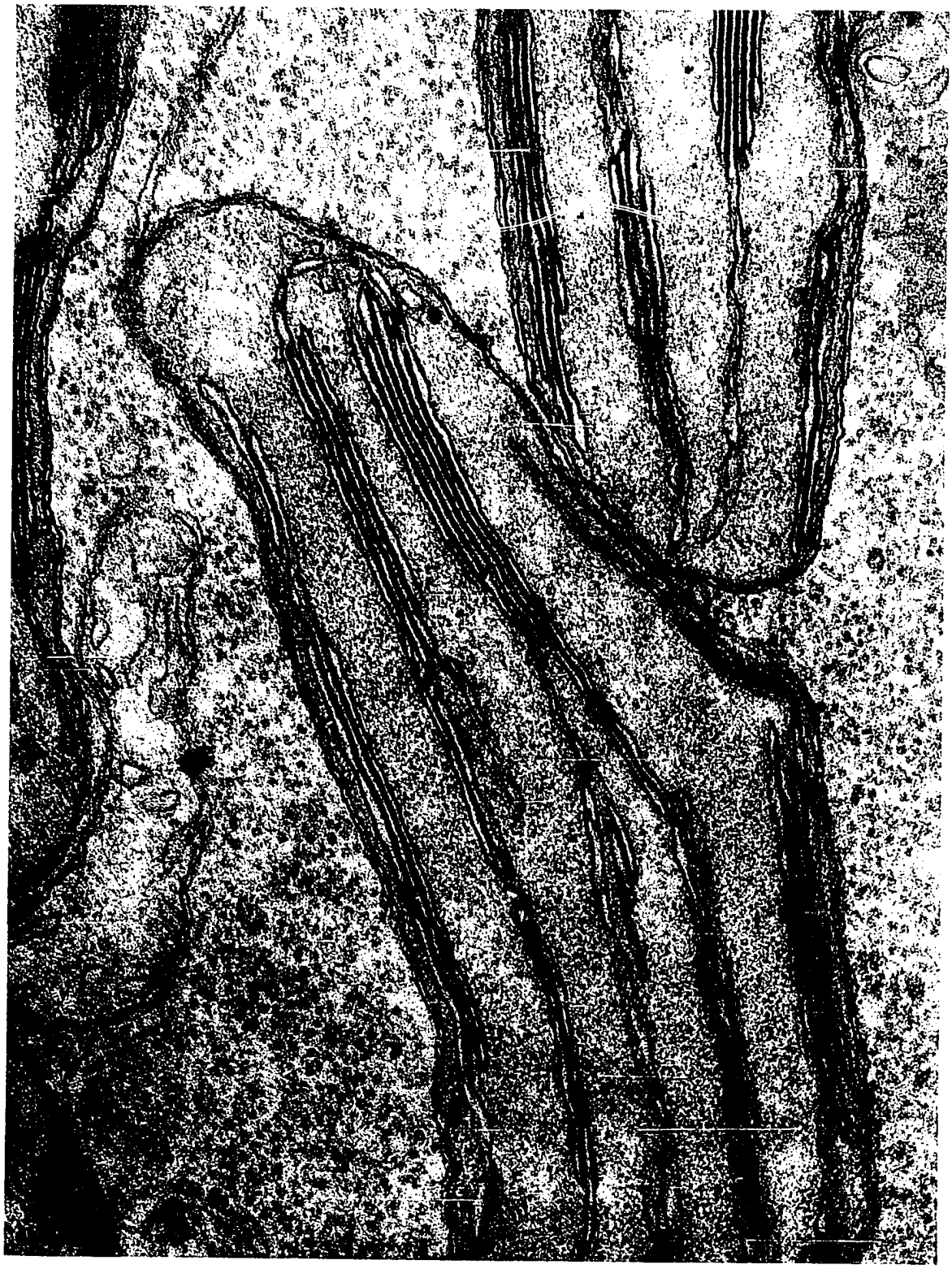


Figure 30. Portions of some cells from young soybean leaf tissue treated with a 0.1 percent concentration of Tergitol P-28 for 40 minutes; glutaraldehyde fixation, post-fixed in $OsO_4$ and stained with lead citrate. Approximately X37,000

Figure 31. Portion of a cell from young soybean leaf tissue treated with a 1.0 percent concentration of Tergitol P-28 for 40 minutes; note the lack of almost any organized cellular structure; glutaraldehyde fixation, post-fixed in $OsO_4$ and stained with lead citrate. Approximately X72,000

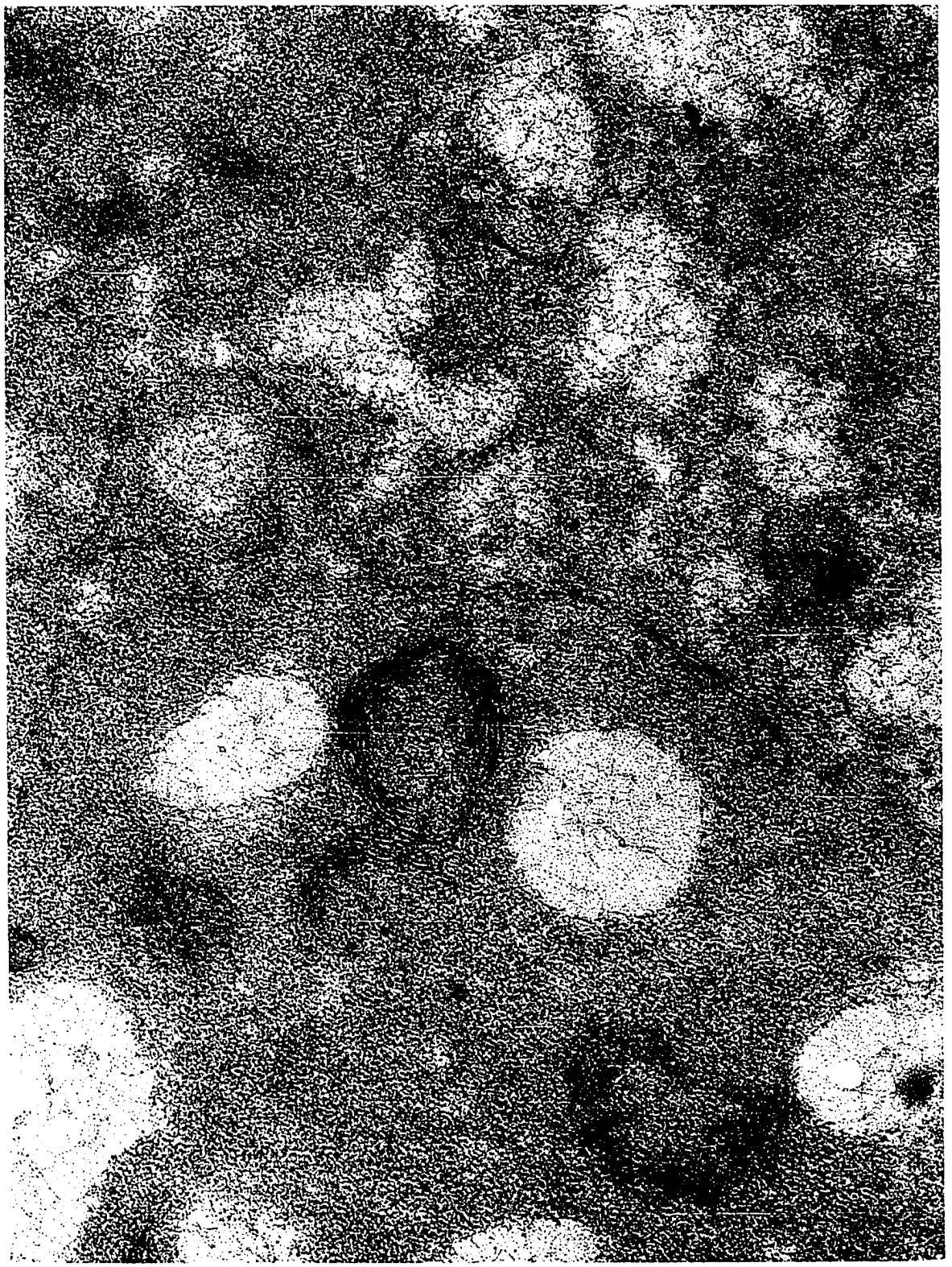


Figure 32. Portion of three cells of a young soybean leaf; note the cell wall (CW), Golgi complex (G), endoplasmic reticulum (ER), ribosomes (R), mitochondria (M), plasma membrane (PM), chloroplast (C), and starch granules (SG); glutaraldehyde fixation, post-fixed in $OsO_4$ and stained with lead citrate. Approximately X72,000


PM
CW
M
SG

Figure 33. Portion of a cell from young soybean leaf tissue treated with a 1.0 percent concentration of Ethomeen T/15 for 40 minutes; glutaraldehyde fixation, post-fixed in $OsO_4$ and stained with lead citrate. Approximately X50,000

Figure 34. Portion of a cell from young soybean leaf tissue treated with a 1.0 percent concentration of Deriphat 151 for 40 minutes; note the general loss of organization of cellular components; glutaraldehyde fixation, post-fixed in $OsO_4$ and stained with uranyl acetate methanol. Approximately X51,000

Figure 35. Cells from young soybean leaf tissue treated with a 1.0 percent concentration of Surfactant DN-65 for 15 minutes; note absence of any defined boundary of cytoplasm and apparently intact starch granules (SG); glutaraldehyde fixation, post-fixed in $OsO_4$ and stained with lead citrate. Approximately X15,000

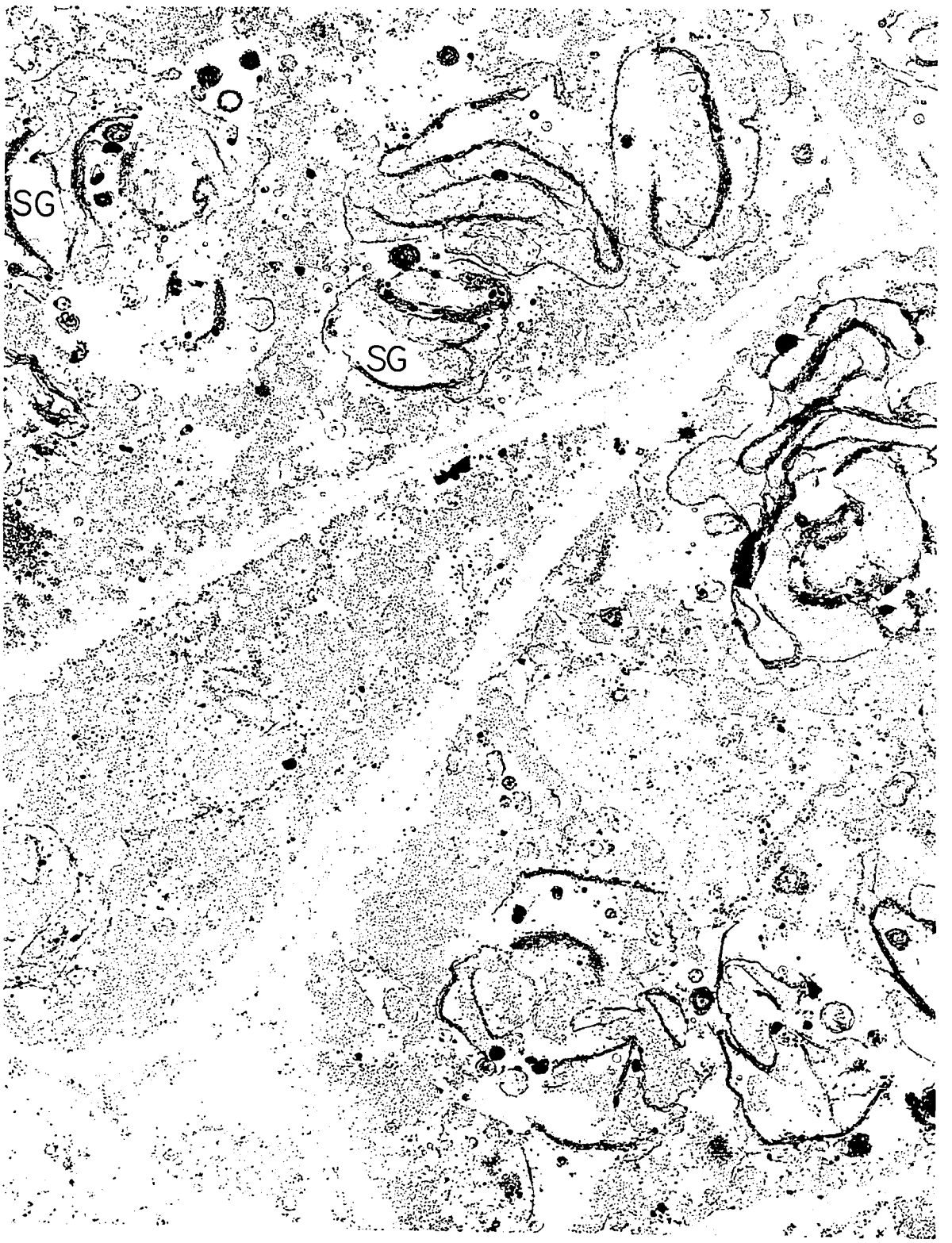

SG
SG

Figure 36. Portion of a cell from young soybean leaf tissue treated with a 1.0 percent concentration of Ultrawet 30-DS for 1 hour; glutaraldehyde fixation, post-fixed in $OsO_4$ and stained with lead citrate. Approximately X72,000

Figure 37. Portion of two cells of a young soybean leaf; note the cell wall (CW), Golgi complex (G), endoplasmic reticulum (ER), ribosomes (R), mitochondria (M), plasma membrane (PM), chloroplast (C), and starch granules (SG); glutaraldehyde fixation, post-fixed in $OsO_4$ and stained with lead citrate. Approximately X72,000


M
PM
CW
ER
SG

Figure 38. Portion of a cell from young soybean leaf tissue treated with a 1.0 percent concentration of Igepal Co-990 for 40 minutes; apparently, no structural deterioration has occurred; glutaraldehyde fixation, post-fixed in $OsO_4$ and stained with uranyl acetate methanol. Approximately X51,000

Figure 39. Portion of a cell from young soybean leaf tissue treated with a 1.0 percent concentration of Pluronic F-68 for 40 minutes; glutaraldehyde fixation, post-fixed in $OsO_4$ and stained with lead citrate. Approximately X72,000

microscope in tissue treated with 1.0 percent concentrations of these two nonionic surfactants.

A final study of the effects of surfactants on plant tissues was done using Elodea as the test material. In this test, terminal shoots of Elodea were selected and immersed, with the exception of the cut end, in either water, 1.0 percent concentration of Pluronic F-68, or 1.0 percent concentration Tergitol P-28 for 40 minutes. After the surfactant treatment, the shoots were rinsed in distilled water and from the endmost leaves, discs were taken using a cut-off hypodermic needle. These discs were fixed as previously described. No detectable damage to the cellular organization was observed in tissue treated with Pluronic F-68 (Figures 40 and 41). Treatments with Tergitol P-28 resulted in structural deterioration comparable to treatments of young soybean tissue (Figure 42).

Figure 40. Portion of a cell from an Elodea leaf; tissue was treated with distilled water for 40 minutes; glutaraldehyde fixation, post-fixed in $OsO_4$ and stained with lead citrate. Approximately X50,000

Figure 41. Portion of a cell from an Elodea leaf; tissue was treated with a 1.0 percent concentration of Pluronic F-68 for 40 minutes before fixation; glutaraldehyde fixation, post-fixed in $OsO_4$ and stained with lead citrate. Approximately X50,000

Figure 42. Portion of a cell from an Elodea leaf; tissue was treated with a 1.0 percent concentration of Tergitol P-28 for 40 minutes; glutaraldehyde fixation, post-fixed in $OsO_4$ and stained with lead citrate. Approximately X37,000

# DISCUSSION

The responses of plant cells and tissues to surfactants, as measured by the bioassay systems used in this investigation, showed among surfactants a probable relationship between hydrophilic and hydrophobic properties and toxicity to plant tissues; revealed a striking similarity in the toxicity patterns of surfactants over the range of the bioassay systems used; and suggested that the toxicity of surfactants to plant tissues may result from direct effects of the surfactant on cell membranes and general cellular organization. The investigation was concerned, not so much with the precise nature of the surfactant action, but with the patterns of toxicity expressed by a number of surfactants over the range of bioassay systems. A study of this nature is a useful requisite for further studies of a more quantitative nature.

Most previous investigations concerned with the effects of surfactants on plants have been conducted either with a limited number of surfactants or with only one or two biological assay systems. Because of the great diversity among surfactants, examination of rather large numbers was necessary to insure that most types were included. Over one hundred surfactants were chosen, representing all ionogenic types and covering a broad range of chemical structure. Seven different assay systems were used to evaluate the responses of plant tissues to some or all of the surfactants studied. Some of the effects of surfactants on cellular proteins and enzyme systems have been characterized by many workers (Putnam, 1948; Yoshioka, 1959) mitochondria (Wittier, 1957) and cytochrome A (Yonetani, 1959) also are affected by surfactants. However, the possibility that a physical effect on permeability may be a common denominator could not be discounted.

Although a number of exceptions were observed, there was a tentative relationship between chemical structure of surfactants and toxicity to plant tissues. The polyoxyethylene content of surfactants was the one factor which could be related most consistently to the observed responses of plant tissues to surfactants. In general, an increase in polyoxyethylene was associated with a decrease in toxicity of the surfactant. This pattern, with some exceptions, was evident in the Triton, Igepal, Ethomeen, and Tetronic families. In the Triton family, as the content of ethylene oxide was increased from 5 to 30 moles per mole of octyl phenol hydrophobe, there was a sharp decrease in toxicity. However, the trend was reversed when less than 5 moles of polyoxyethylene were present. This trend agreed, in general, with Cornforth et al. (1955), who showed that the antituberculous activity is related to length of the polyoxyethylene chain. These workers found that antituberculous activity was greatest when the hydrophilic chain consisted of 10 to 20 ethylene oxide groups; when the chain length consisted of 45 to 90 units, tuberculous activity was actually enhanced. McWhorter (1963a) showed that herbicidal activity of Dalapon was greater when combined with a surfactant containing 9 to 10 moles of ethylene oxide than when the surfactant contained 15 to 30 moles of ethylene oxide.

In this study, a number of exceptions were found which precludes a general statement relating chemical structure of surfactants to toxicity to plant tissues. Although increased toxicity was usually associated with a decrease in ethylene oxide content, there were some exceptions. This was illustrated between two members of the Ethomeen series; the member having the least content of ethylene oxide was the least toxic. Another example was found in the Triton series. The reversal of the usual pattern

occurred with members containing less than 5 moles of ethylene oxide per mole of hydrophobe.

The responses of plant tissues to both toxic and non-toxic surfactants were remarkably similar with each of the biological assay systems utilized. Surfactants which inhibited germination of seeds, also prevented growth of corn seedling radicles and soybean leaves, were toxic to plant roots in water cultures, greatly increased the permeability of beet root cells to anthocyanin pigments, and produced severe disorganization of the cellular content of soybean and Elodea leaves. Similarly, the non-toxic or mild surfactants produced no effects in any of the bioassay test systems. Differences in sensitivity were evident among the bioassay methods, particularly with respect to the concentrations of surfactants necessary for significant plant tissue or cell responses and with the plant species utilized.

In the seed germination tests, oats were the most sensitive species tested, with corn, radish, and giant foxtail considerably less sensitive. The same patterns of surfactant toxicity revealed in seed germination were evident in studies on the response of corn roots to surfactants. However, the sensitivity of the surfactant effect on corn radicle growth was much greater than that observed with the seed germination bioassay. When surfactants were included in a water culture medium, those which were most toxic in germination and root elongation tests were also most inhibitory to growth of soybeans in water culture. Toxic surfactants included Alrowet D65, Ultrawet DS, and Sterox SK. Others which were found to be generally non-toxic and likewise produced no ill effects on soybeans in water culture were Igepal Co-990, Pluronics F-38 and F-68. There were, in general, fewer effects of surfactants when applied as foliage treatments to soybean

seedlings at concentrations of 0.1 percent or less. However, the patterns of toxicity expressed by treatments with surfactants at 1.0 percent concentration revealed, in general, the same patterns as expressed by germination and corn radicle elongation studies.

Responses of beet root tissue to surfactants showed that most of the surfactants which were highly toxic in previous bioassays, were active also in increasing the permeability of beet root cells to anthocyanin pigments. In a number of families, which varied in hydrophilic-hydrophobic balance, the general decrease in toxicity with an increase in ethylene oxide was not evident, reflecting a possible limitation to the sensitivity of the beet tissue bioassay method.

Although only a few surfactants were evaluated in the bioassay involving use of the electron microscope to observe cell microstructure, the same general patterns of toxicity among surfactant types, observed with plant responses, were repeated in this test method. Those surfactants already identified as toxic in previous bioassay systems produced extensive disorganization of the cellular contents of cells of soybean and Elodea leaves, following various periods of surfactant treatment. Similarly, the non-toxic or mild surfactants produced no detectable changes in cellular structure. Experiments which included various periods of time and/or different concentrations of surfactants revealed that both higher concentrations of surfactants and longer periods of exposure contributed to a greater loss of cellular structure. At least one surfactant was found within each ionogenic type which was effective in destroying cellular organization. The destructive properties of at least one of these surfactants were similar on different species of plants. Leaf tissue

from young soybeans, Elodea, and tobacco treated with 1.0 percent concentration of Tergitol P-28 for 40 minutes revealed comparable structural deterioration in each tissue. Mild or non-toxic surfactants which had no appreciable effect on plant growth and development produced no detectable effects on the ultramicrostructure of leaf tissue. However, the possibility remains that there was little or no penetration by the mild surfactants.

The direct applications of the findings of this study to practical methods of weed control cannot be visualized either in terms of using surfactants to destroy weed seeds in the soil, or in direct use of surfactant sprays as herbicides. However, the strong implications that the phytotoxic properties of the surfactants may result from the direct effects of surfactants on cellular microstructure and membrane permeability, suggest additional uses for surfactants in the herbicide technology besides their presently conventional use in formulation. Moreover, the results of this study offer reasonable explanations of previously reported studies (Staniforth and Loomis, 1949; Jansen et al., 1961), wherein successive increments of surfactant were shown to increase the activity of herbicides, even though maximum reduction of the surface tension of the spray solutions was reached with the first increment of surfactant added. The probable effects of relatively high concentrations (1.0 to 5.0 percent) of surfactants in herbicide spray solutions on the permeability of cells in plant leaves, and hence, possibly on their permeability to herbicides, are suggested by the results of the present work.

Possible practical uses of surfactants in the herbicide technology suggested by this study include the use of biodegradable surfactants to enhance the effectiveness of aquatic herbicides, the use of surfactant

solutions as primer sprays to modify the differential response of crop and weeds to a follow-up herbicide application, thus in effect extending the margin of selectivity, and perhaps the use of non-toxic surfactants to improve the formulation of present herbicides. The similarity of the response of any individual surfactant with all the bioassay systems indicates some problems in the development of selective surfactants for uses suggested above.

Future research needed to test these concepts must include empirical testing in the greenhouse and the field and laboratory studies designed to determine the quantitative aspects of surfactant phytotoxicity and to delineate the effects, if any, of surfactants on permeability of cells to herbicides.

## SUMMARY

Patterns of surfactant phytotoxicity were studied by observing the responses of selected biological assay systems. These systems demonstrated the effects of surfactants on seed germination, elongation of corn seedling radicles, growth of soybean seedlings following surfactant application to either foliage or roots, loss of permeability of cells of beet root tissue and modifications of the microstructure of plant leaf cells following exposure to surfactants. Approximately one hundred surfactants, representing all four ionogenic types and covering a broad range of chemical structures, were evaluated by one or more assay methods.

Among most families of surfactants a decrease in toxicity was associated with an increase in polyoxyethylene content per mole of hydrophobe. In a number of cases, the hydrophobe was influential in determining surfactant toxicity. In some cases, slight changes in chemical structure of the hydrophobe resulted in significant changes in observed toxicity patterns. This was illustrated clearly in the observed effects of the Ethoquad surfactants. In this family, members which contained two moles of ethylene oxide displayed a range of toxicities which were dependent upon the identity of the hydrophobe.

It was not possible to classify surfactants as toxic or non-toxic on the basis of ionogenic grouping. Within the nonionic type surfactants, members were observed which exhibited various levels of toxicity ranging from extremely toxic effects of the Triton series to the relatively non-toxic effects of the Igepal Co- series. Actually, a broad spectrum of toxicity to plant cells was evidenced within the Triton series; toxicity

decreased as the content of ethylene oxide per mole hydrophobe increased. Cationic type surfactants also contained members which exhibited various degrees of toxicity to plant tissues as evidenced within the Ethomeen and Ethoquad series. Ethomeen 18/60 was appreciably less toxic to plants than other members of the Ethoquad series; Ethoquad 18/12 also was less toxic than other members of the Ethoquad series. Although all of the amphoteric surfactants tested showed some detrimental effects to plants, different responses with various members of this group were observed. Among the anionic surfactants used, the patterns of response to plants were not clear-cut.

In general, the effects of surfactants were similar in each of the biological assays used, but there was some variation in sensitivity among the various systems. Root elongation was the most sensitive of the test systems, including responses of tissues or plant responses.

Studies of the effects of selected surfactants on the ultramicrostructure of cells of leaf tissues from young soybeans or Elodea revealed substantial losses of cellular organization when exposed to surfactants which were found to be toxic in previous assay systems. Surfactants exhibiting no toxicity in these assay systems likewise had no detectable effect on the ultramicrostructure of cells of soybean or Elodea leaf tissue.

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